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A COURSE OF TWELVE

ELEMENTARY LECTURES

ON

GALVANISM;

ILLUSTRATED

WITH UPWARDS OF 100 ENGRAVINGS

OF

Experiments and Apparatus.

BY WILLIAM STURGEON,

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PREFACE.

THE Lectures which now, for the first time, are brought before the public through the medium of the press, are arranged in nearly the same order as that in which I am in the habit of delivering them. I have, however, introduced some few experiments whose resulting phenomena are not sufficiently striking to be introduced with advantage at the lecture table; and there are some that I have not had an opportunity of repeating: such, for instance, as those on the heads and trunks of oxen, and on the human body. I have, however, had an opportunity of Galvanizing the bodies of four young men, who were drowned by falling through the ice, at Woolwich; but two hours having been occupied, by the usual routine of medical treatment, before the batteries were employed, there was not the remotest chance of obtaining beneficial results. Notwithstanding this loss of time, however, the bodies, with the exception of one, were still alive to the Galvanic influence. Some of the four opened their eyes and moved the lips; and one of them bent the elbow when the current traversed the arm from the shoulder to the hand. But no motions of the chest could be produced by any applications of the battery that were tried.

Throughout the whole of the course, I have selected such facts only, as best suited my purpose, and arranged them in that order which appears to me best calculated for teaching the rudiments of the science; and in order to keep in view the analogy which subsists in the phenomena emanating from different sources of electric action, I have introduced several original experiments never before published.

In the electro-chemical department, I have endeavoured to simplify the theoretical explanations by retaining familiar terms and long established principles. I am aware that there are some few philosophers of the present day, whose theoretical views would appear to differ widely from those which I have attempted to maintain; but as I have not yet seen any thing like a *clear* and *unequivocal* code of laws, in any of the writings of those with whom I differ, nor even an attempt worthy of the name, to substantiate their hypothesis, I can see no cause for abandoning the good opinion which I entertain of a theory which is based on well established laws, and embracing principles applicable to every known phenomenon in electricity, and well calculated for explanation.

Various means have been resorted to for measuring the relative degrees of Galvanic force; but as every attempt has failed, I have introduced no instrument of that class, excepting the galvanometer; and even that instrument, for no other purpose than showing its use in ascertaining the electrical *relations* of metals, and of Galvanic combinations, without any intention whatever of *measuring their difference* of force

As this work is neither a history nor a treatise, the names of many distinguished philosophers who have contributed to the advancement of Galvanism are left unnoticed, the most eminent of whom are the late Dr. Henry, of Manchester; Donovan, of Dublin; and Humboldt, Œrsted, Berzelius, De Luc, Arago, Biot, Ampere, Dessaignes, Gay Lussac, Thenard, Dela Rive, and others, on the Continent.

That there are errors in the work, will necessarily be expected; but they are mostly of a typographical character, few in number, and easily rectified by the reader, the only important one being "Basium" instead of "Barium," page 153. The experimental department, I believe, will be found free from error; and I have endeavoured to simplify the whole process in each experiment, in order that the amateur may find no difficulty in his attempts at repetition.

In fact, I have endeavoured throughout the whole work, to simplify the principles of Galvanism so as to be comprehensible to every capacity; and to place before the student, a series of facts, which, both for number and order of arrangement, has no precedent in the English language.

For the information which I possess respecting the application of Galvanism to Engineering, I am especially indebted to General Pasley; by whose permission I have had an opportunity of being present at some of his experiments in the river Medway; and by whose instructions I have been favoured with every facility for becoming acquainted with the arrangement of the apparatus, and every part of the process; and I with pleasure avail myself of this opportunity of acknowledging these, and many other marks of kindness with which I have been honoured by that highly distinguished scientific officer.

Institute of Natural and Experimental Science,

Manchester, July 20*th*, 1843.

CONTENTS.

LECTURE I.

LECTURE II.

LECTURE III.

LECTURE IV.

LECTURE V.

LECTURE VI.

LECTURE VII.

LECTURE VIII.

LECTURE IX.

LECTURE X.

LECTURE XI.

LECTURE XII.

APPENDIX.

ELEMENTARY

LECTURES ON GALVANISM.

LECTURE I.

The field of science that opens to our view, under the combined terms Galvanism and Voltaism, otherwise called Galvanic and Voltaic Electricity, is so extensive in its domain; so fertile in the number, diversity, and importance of its phenomena, that, to the philosophical world, it has become a treasure of inestimable value, by expanding its boundaries to an immense extent, and shedding a refulgent light over mysteries which the operations of the physical world had presented from the earliest times of philosophical reasoning, till the period which gave birth to researches in this almost boundless region of Electricity.

The brilliant series of discoveries which had been made by the employment of the electrical machine and extensive batteries of Leyden jars, had just ceased to develope their most resplendent phenomena; and but a short series of years had elapsed to give philosophers an opportunity of becoming familiar with what had been done in that department of Electricity, when Madame Galvani, the wife of an eminent physician and philosopher of Bologna, accidentally observed a novel phenomenon, which gave rise to new trains of

reasoning, and to experimental results which, eventually, have been the means of directing the minds of philosophers to entirely new and distinct branches of study.

The discovery which Madame Galvani had the good fortune to make, happened about the year 1790; and is, perhaps, as singular, with respect to the circumstances under which it occurred, as any recorded in the history of scientific events. It appears that this lady, who, for some time previously, had been in a declining state of health, was requested by her medical advisers to use stewed frogs as an article of diet, being a customary restorative in that country. One day a few of Galvani's friends being assembled in his laboratory, began to amuse themselves by taking sparks from the prime conductor of an electrical machine, which stood on the same table on which was placed a dish, containing a number of frogs already dressed for cooking. Madame Galvani being present, and intently looking at these delicate morsels, was struck with the occasional and sudden convulsive twitchings which some of them exhibited whilst the machine was in action. Observing these novel appearances still closer, she detected a correspondence, in point of time, between the convulsive movements and the emission of sparks from the prime conductor: and observing also, that the blade of a scalpel, which accidentally lay on the edge of the dish, touched some of these little animals, the idea arose in her mind that they were convulsed by electrical agency, which further inquiries proved to be the fact.

Galvani was not present at the time, but was informed of the phenomena by his lady, immediately after his return. A short time previous to this discovery, he had instituted a series of experiments, with a view of proving that muscular action is effected by electrical agency; and being still engaged in the inquiry, he was delighted to receive the intelligence, considering it as corroborative of the

physiological views he had taken. Elated by this supposed confirmation of his hypothesis, Galvani became inspired with new ardour in the prosecution of his researches: and by pursuing the new line of investigation which his wife's discovery had pointed out, his future experimental undertakings were attended with the most happy results.

Galvani first entered on a series of experiments upon dissected frogs, which he submitted to the action of electric sparks; and by this means he soon verified his lady's conjecture respecting the cause of the convulsive motions which she first observed amongst those which were accidentally electrized in the laboratory. These experiments were pursued with different degrees of electric action, until it was discovered that the minutest quantity would convulse the delicate parts of frogs, when properly prepared for the experiments. Such, for instance, are the hind legs and thighs, with the crural nerves laid bare, and attached to a small morsel of the spine. These were found to be the parts most sensitive to electric action; and so exquisitely susceptible are they of electric excitement, that they appear to constitute a more delicate test for feeble electric action than a Bennet's gold-leaf electroscope.*

The success which attended these experimental inquiries redoubled Galvani's diligence, and induced him to prosecute them still further. In his next series of experiments the electric action of the atmosphere was employed in place of that excited by artificial means; and the muscular contractions and nervous irritability were displayed in prepared frogs, and other recently killed animals, as decidedly from the one source of electric action as from the other.

Whilst contemplating on the great variety of means by which he was enabled to produce the convulsive movements in recently killed animals, his

* For a description of this instrument see vol. I., "Electricity," p. 40.

previous views concerning electro-muscular action began to expand, so as to embrace the whole animal frame as a natural electrical machine, in a continual state of excitement; and which, like the rubber and glass parts of the ordinary electric machine, has its muscular and nervous systems in different electric conditions. These grand views of animal electricity, which were developed to the mind of so excellent a physiologist, and dexterous manipulator as Galvani, by the experimental results he had already obtained, could hardly fail to disclose other means of experimenting than those he had hitherto pursued. Accordingly we find that, in order to test the accuracy of his new hypothesis, he laid aside all extraneous electric action, and operated with that only which he thought naturally belonged to the animals themselves.

Keeping in view the supposed distinct electric conditions of the nervous and muscular systems, he laid bare the crural nerves of a frog, and having removed all muscular matter from between the thighs and the dorsal spine, he made a communication between these two parts by means of a thin metallic wire, which operated as a discharging rod, and the animal was convulsed as decidedly as by the former modes of experimenting. In this case, Galvani supposed that the animal was agitated by a discharge of its own electric fluid, which proceeded through the metallic arc from the nerves to the muscles, as in the discharge of coated glass from the positive to the negative side.*

Galvani varied the character of his conducting arc, by employing gold, silver, copper, zinc, &c.; but in all cases the convulsive motions were produced; and to a greater extent, as the animal was in a more vigorous condition. Fortunately for this branch of science, Galvani not only employed different metals for the simple conducting arc, but combined the different metallic wires in such a manner as to form

* See "Lectures on Electricity," p. 100.

compound arcs; by which means one metal could be applied to a muscle and the other to a nerve at the same time, the metals themselves being also in contact with one another. By the employment of these compound arcs it was soon discovered that the convulsive motions were displayed in a much higher degree than by the application of a single metal alone.

Although these novel modes of experimenting yielded results in perfect accordance with their author's views of animal electricity, it was not enough for this profound and sagacious inquirer to rest his hypothesis solely upon them; for as he had employed metals in conjunction with the animal fibres, it was necessary to inquire how far these were concerned in the process, since there was a possibility, at least, that each individual metal was endued with an electric action peculiar to itself, which, if true, would be a means of modifying the results. Galvani now partially insulated the metallic arcs from the parts of the animal on which he operated, by means of inferior conducting substances, such as water and other aqueous liquids, and found that, although the phenomena were not of so striking a character as when the metal actually touched the subjects of experiment, the convulsive movements were still as decisively produced. He even proceeded so far in these minute inquiries as to dispense with the metal entirely; and convinced himself that water alone performs the function of a metallic arc, though in a less degree. Notwithstanding, therefore, the interference of any electric action that might be due to the metals, when those bodies were employed, the phenomena exhibited during their absence could not be attributed to that source of excitement. Galvani very properly considered them as corroborative of his hypothesis, and believed that he was justified in publicly announcing them as such.

The announcement of Galvani's discoveries and extensive experimental inquiries in this novel branch

of research, excited the attention of every physiologist of eminence throughout Europe ; several of whom immediately entered on a repetition of the novel facts, and examined them in the most scrupulous manner. Professors Valli, Fowler, Pfaff, Volta, and many other naturalists, entered ardently into the new path of inquiry, and their labours soon enriched the science with novel modes of experimenting, with an abundance of facts, and with different modes of reasoning on them. But the most valuable results at this period of the inquiry emanated from the labours of M. Volta, then professor of natural philosophy at Como, and one of the most eminent electricians of his day.

Having repeated Galvani's experiments, and satisfying himself with the correctness of the results, Volta turned his attention to other modes of experimenting, from which he developed facts which he fancied would overturn the whole system of reasoning established by Galvani, and soon became the most formidable opponent to the hypothesis of animal electricity. Volta showed, though anticipated by Cavallo, that the simple contact of the dissimilar metals is sufficient to develope an electric action appreciable by the electroscope : and upon this simple fact alone he insisted that the whole of the phenomena attributed to animal electricity by Galvani, might easily be traced to the electricity of the metals which were employed in the experiments.

The professor of Bologna replied to this opposition of his hypothesis by new experiments, and extended reasoning upon them : but notwithstanding the clearness of his statements, and the unequivocal character of his experimental results, even when no metal was present, Volta strenuously combated the hypothesis of animal electricity : and although he became convinced, even by his own inquiries, that other heterogeneous bodies, besides those of a metallic character, would develope electric action by simple contact alone, and was forced to acknowledge

that the muscular and nervous fibre came under the denomination of heterogeneous bodies, and that by their simple contact electricity would be developed; and thus absolutely proved the correctness of those theoretical views which he was attempting to obliterate, still he persisted in denying Galvani any share of merit for his hypothesis, even though he found the principles on which it was based convenient for his own purpose, and even indispensable for the completion of an hypothesis which he was then building for himself, from the frame-work of which they could not possibly be excluded.

Volta, however, who, in his letters to Cavallo, gave the first intelligence of Galvani's discovery to the philosophers of this country, gives every degree of credit to the Professor of Bologna for the acuteness of his inquiries, the dexterity of his manipulations, and the novelty of the phenomena he had developed. He even acknowledges, in his first letter, that Galvani had discovered "*an animal electricity, properly so called*, appertaining not only to frogs, and other cold-blooded animals, but also to all warm-blooded ones, as quadrupeds, birds, &c.; a discovery," says Volta, "which makes the subject of the third part of his (Galvani's) work a subject quite new and interesting."*

Volta had hitherto alluded to the earliest of Galvani's experimental inquiries, in which the electricity of the machine and that of the atmosphere had been employed; and closes his account of them with the following uncourteous remarks: "It was chance that presented to M. Galvani the phenomenon just described, but at which he was more astonished than he needed to have been, had he given due attention to the effects of electric atmospheres."

* Volta's Letters to Tiberius Cavallo, F. R. S. Phil. Trans. for 1793. These letters were written at PAVIA, to the University of which Volta had removed from that of COMO.

The doctrine of "Electric Atmospheres" has been explained and experimentally illustrated in my twelfth Lecture on Electricity. It is a doctrine that cannot be too well studied by those who are desirous of becoming acquainted with the general principles of electric action: and as it enters essentially into that branch of Electricity of which we are now treating, it ought to be borne in mind in almost every step that we take, as we proceed in the theoretical illustrations. The action of electric atmospheres, here spoken of by Volta, as explanatory of Galvani's experiments, was no doubt the true cause, when *primarily* considered, though not the *immediate* cause of the spasmodic movements exhibited: for the electrosphere* of the prime conductor, whether that of the machine or that of the kite string, produced electro-polarity in the scalpel, or other metal, in connexion with the frog; and as these metals could not sustain the electric pressure which occasioned their polarity, without suffering loss, a portion of electric fluid escaped from them to the frog, and returned as a *secondary* discharge, simultaneously with each *primative* discharge of a spark from the prime conductor. The cause of these *secondary* discharges is precisely the same as that of *lateral* discharges of the third kind, as illustrated in my eleventh Lecture on Electricity, p. 209.

In referring to Galvani's second class of experiments, in which no extrinsic electric action was employed, Volta says, "Thus he happily evinced the existence of a *true animal electricity* in almost all animals. It appears proved indeed by these experiments, that the electric fluid has a continual tendency to pass from one part to another of a living organized body, and even of its lopped members, while they

* I have taken the liberty of employing the term "Electrosphere," as being more appropriate than "Electric Atmosphere," to express the electric state of the surfaces and vicinal space of electrized bodies.

retain any remains of vitality: that it has a tendency to pass from the nerves to the muscles, or *vice versa*, and that muscular motion is due to a like transfusion, more or less rapid. Indeed it seems that there is nothing to be objected, either to the thing itself, or to the manner in which M. Galvani explains it by a kind of discharge similar to that of the Leyden phial."

The opinions here stated are in perfect accordance with those of Galvani. The succeeding paragraph of Volta's letter, however, evinces a very different feeling to the doctrine which, just before, he had seemed to admire; although to an electric logician it would be difficult to ascertain the cause. There is certainly nothing in the following passages of Volta's letter, which could in the least tend to vindicate such a sudden and total change in his views of Galvani's hypothesis.

"M. Galvani," says Volta, "following up the idea he had formed after his experiments, and to follow, in every point, the analogy of the Leyden phial and the conducting arc, *pretends* that there is naturally an excess of the electric fluid in the nerve, or in the interior of the muscle, and a corresponding defect in the exterior, or *vice versa;* and he supposes consequently that one end of that arc ought to communicate with a nerve which he considers as the conducting thread, or knob of the phial, and the other end with the exterior of the muscle. But had he but a little more varied the experiments, as I have done, he would have seen that this double contact of the nerve and muscle, this imaginary circuit, is not always necessary. He would have found, as I have done, that we can excite the same convulsions and motions in the legs, and the other members of animals, by metallic touchings, either of two parts of a nerve only, or of two muscles, and even of different points of one simple muscle alone."

"It is true," continues Volta, "that we succeed not quite so well in this way as in the other; and that in this case we must have recourse to an artifice,

which consists in employing two different metals, which is not necessary in experimenting after Galvani's method, at least while the vitality in the animal, or in its amputated members, is in full vigour: but in short, since, with the armings of different metals applied, either to the nerves only, or to the muscles alone, we succeed in exciting contractions in these, and the motions of the members, we ought to conclude that if there are cases (which, however, appears very doubtful) in which the pretended discharge between the nerve and the muscle is the cause of muscular motion, there are also circumstances, and more frequently, in which we obtain the same motions, by a quite different way, a quite different circulation of the electric fluid. Yes, it is a quite different sort of method of the electric fluid, of which we ought rather to say we *disturb* the equilibrium, than restore it, in that which flows from one part to another of a nerve, or muscle, &c., as well interiorly by their conducting fibres, as exteriorly by means of applied metallic conductors, not in consequence of a respective excess or defect, but by an action *proper* to these metals when they are of different kinds. It is thus that I have discovered a new law, which is not so much a law of animal electricity, as a law of common electricity; to which ought to be attributed most of the phenomena which would appear, from both Galvani's experiments and mine, to belong to a *true spontaneous animal electricity*, but which are not so; but are really the effects of a very weak artificial electricity."

There does not appear in any part of this reasoning of Volta, nor in the experiments which he brings forward in support of it, any cause whatever to detract from the hypothesis of Galvani. Volta himself, acknowledges that when a muscle only, or a nerve alone, is operated on, that in order to succeed in producing the convulsive motions, "we must have recourse to an artifice, which consists in employing two different metals, which is not necessary in

experimenting after Galvani's method." The reason is obvious. By Galvani's method the muscles and the nerves were the source of electric action; whilst by Volta's "artifice," (a method of experimenting first employed by Galvani,) the dissimilar metals constituted the electric source. The principal part of Galvani's hypothesis which Volta seemed so desirous to overturn, is that of the *animal electric charge* being similar to the charge of a Leyden phial.

At the time this controversy was carrying on, but very little, if any thing, was known, respecting the different electric states of conducting bodies when in close contact with one another; the general opinion being that insulation, to some certain extent, was absolutely necessary to maintain their respective conditions: and as the Leyden phial showed this effect in the most prominent manner, there can be no wonder at Galvani adopting the coatings of that instrument, as a comparison to the nervous and muscular electric conditions which he thought to exist; although, at the same time, he intended his words to imply nothing more than that these systems were *relatively* in different electric states; a fact well attested both by his own experiments, and by those of other philosophers, and ratified by analogy, even from the experimental labours and the reasonings of Volta himself.

The doctrine of Franklin holds it as a principle, that the same bulk of each kind of matter has, naturally, a certain quantity of the electric fluid belonging to it, which may be called its *specific quantity*: and the experiments of Lichtenberg and Cavallo, several years prior to the discovery of Galvanism, showed that bodies, both conductors and non-conductors, were in different electric conditions during contact. I have already shown a specimen of this fact, by a very beautiful experiment, towards the close of my Lectures on Electricity, and shall have to allude to several others of the same kind in the present course.

That there is the faculty of keeping in different electric conditions, the organism of living beings, is amply manifested in the Torpedo, and the Electrical Eel of Surinam, whose shocks, especially of the latter fish, are too violent to be received without experiencing considerable pain. The benumbing sensations produced by approaching the hands towards different parts of the Torpedo, have been known as a fact from time immemorial: and if this faculty was not attributed to an electrical influence previously to 1772, Mr. Walsh's experiments at Rochelle, about that time, were sufficiently decisive on that point. In Mr. Walsh's letter to Dr. Franklin, dated Rochelle, 12th July, 1772, he observes, "It is with particular satisfaction I make to you my first communication, that the effect of the Torpedo appears to be absolutely electrical." He then proceeds to say, "I will not at present trouble you with the detail of our experiments, especially as we are daily advancing in them; but only observe, that we have discovered the back and breast of the animal to be in *different* states of electricity." "By the knowledge of this circumstance we have been able to direct his shocks, though they were small, through a circuit of four persons, all feeling them; likewise through a considerable length of wire, held by two insulated persons, one touching its lower surface, the other its upper. When the wire was exchanged for glass, or sealing wax, no effect could be obtained; but as soon as it was resumed, the two persons became liable to the shock. These experiments have been varied in many ways, and repeated times without number, and they all determined the choice of conductors to be the same in the Torpedo as in the Leyden phial. The sensations, likewise, occasioned by the one and the other in the human frame are precisely similar. Not only the shock, but the numbing sensation which the animal sometimes dispenses, expressed in the French by the words *engourdissement* and *sourmillement*, may be exactly imitated with the

phial, by means of Lane's Electrometer,* the regulating rod of which, to produce the latter effect, must be brought almost into contact with the prime conductor which joins the phial."

I have made this copious extract for the purpose of showing that Galvani's hypothesis of animal electricity was well supported by the facts established in Mr. Walsh's experiments, at least eighteen years previous to Madame Galvani observing the commotions in the frogs; and the electric powers of the Torpedo were well known to both Galvani and Volta, at the time of their controversy respecting the electricity of other animals.

Besides the well-established proofs of the existence of dissimilar electric organisms in these inhabitants of the waters, there are no less direct proofs of the electric agency residing in other animal bodies. The experiments of Professors Valli and Aldini, in which no metals were employed, led both of these eminent physiologists to the conclusion, that the living animal is endowed with electric powers: and they showed by the most satisfactory experiments, that these powers are brought into a state of activity, and capable of convulsing the animal in which they reside, by the mere contact of a muscle with a nerve. But it would be needless to multiply facts in this place, since we shall have to advert to them again as we proceed in our next lecture, in which we shall show the most efficient methods of making the experiments already alluded to, and several others, which not only favour the hypothesis of animal electricity, but which carry conviction to the unprejudiced mind, that, as in metals and other inorganic matter, so in organised inanimate, and all animated, beings, there resides a specific electric charge; that this charge is not uniformly distributed even in one and the same individual body; and that,

* For a description of this instrument, with its application to the Leyden phial, see "Lectures on Electricity," p. 172.

in the animal system, the extent of the charge in the nerves is very different to that in the muscles; so that each individual organism in the animal body has its specific charge of the electric matter.

Notwithstanding the irrefutable facts demonstrative of animal electricity, that were brought to Volta's notice, he still persisted in maintaining the contrary opinion, and with the most assiduous perseverance he multiplied and diversified his experiments in order to give it support. Volta's theoretical views were now so steadfastly centred in the electricity of the metals, that for a while he made no enquiries in which they were not employed; and his experiments, eventually, led to the grandest results.

Volta having excited convulsive motions in the muscles and the members of both small and large animals, without laying bare any nerve, by the application of dissimilar metals to the muscles stripped of their integuments, began to think of doing the same in the human subject; and after pretending to devise a variety of plans to operate on the living body, he claims for himself the credit of discovering a mode of experimenting, which happened to be well known to the philosophers of Europe many years previously.

"Having covered the tip of the tongue and a part of its upper surface, to the extent of some lines, with tin leaf, he applied the convex part of a silver spoon more advanced on the flat of the tongue, and inclined the spoon till its handle came in contact with the tin foil." By this mode of experimenting, Volta says that he "expected to see the trembling of the tongue, and for that purpose placed himself before a looking-glass. But the expected motions did not take place: however, he felt instead of it, a very unexpected sensation, a pretty sharp sensation on the end of the tongue."*

SULTZER, a German metaphysician, published

* Volta's letter to Cavallo; Phil. Transactions for 1793.

the very same experiment in his "Theory of Pleasures," in the year 1767. This author states, that "if two pieces of metal, one of lead the other of silver, be joined together at their edges so as to form but one plane, and thus placed on the tongue, a taste similar to that of vitriol of iron will be experienced. But when either piece of metal is applied separately to the tongue, no such taste is produced." Hence this experiment, which by some writers is ascribed to Volta, is obviously due to Sultzer, who published it twenty-five years previous to the date of any of Volta's enquiries on this subject.

When Volta perceived the "sharp taste on the end of his tongue," he appears to have been "much surprised at the event." When speaking of Galvani's earliest experiments, Volta had remarked, that "he was more astonished than he needed to have been, had he given due attention to the effects of electric atmospheres." The same remark is applicable to his own astonishment at the effect produced on his tongue by a repetition of Sultzer's experiment. Indeed, the remark retorts on Volta in a still more forcible manner, when it is considered that Galvani's experiment was perfectly original, and no similar effect to that produced was then known; whilst the Sultzerian experiment with its attendant phenomenon, were well understood when Volta enrolled them amongst his own list of discoveries.

Indeed, the Sultzerian experiment had been repeated and modified in different ways by Creve and Fabroni, prior to its repetition by Volta. The former physiologist considered that in the Galvanic experiments their effects were due to chemical irritation, and not to any electrical influence. He says, that, "when a communication is established between two metals, or between a metal and charcoal, the water by which the muscles or the nerve is surrounded is partly decomposed. The oxygen, one of its elements, having a greater affinity with the charcoal, or with the metal, than with the hydrogen, quits the

latter. The decomposition merely takes place in that portion of water immediately in contact with the metals; but the sphere of influence which this decomposition possesses is not enclosed by such limitation, as the following experiment amply proves.

"Place a metallic apparatus in a glass filled with water, and afterwards introduce the tongue to the liquid, at the distance of an inch from the metals. An acrid and astringent impression is produced, characteristic of metallic irritation. The tongue is affected because it is placed within the sphere of action of the decomposed water; and the nearer it is brought to the place where the metals are in contact with each other, the greater degree of sensation is experienced."

It is somewhat singular that in this early part of the enquiry, Creve should have fallen upon one of the most important facts in Voltaic Electricity. The decomposition of the water in connexion with the metals, is a necessary condition of continued electric currents from every form of Voltaic apparatus hitherto known. The superior action on the tongue, when near to the point of metallic contact, is also a fact perfectly analogous to other phenomena, now well known to proceed from a similar arrangement of metals and liquid matter. And to this physiologist is justly due, not only the discovery of this fact, but also the chemical hypothesis of Galvanic action, which are generally supposed to have emanated from the researches of other philosophers, of a much later period of the history of the science.

The theoretical views of Fabroni were analogous to those of Creve, attributing the whole phenomena, both Galvanic and Sultzerian, to chemical operation. In repeating the Sultzerian experiment with his tongue partially dried by wiping it with a towel, Fabroni discovered that the sensation was reduced to such a degree as scarcely to be distinguishable. Hence he concluded that the saliva, the lymph, or some kind of humidity, had an influence in producing

the full effect; and that there is a high degree of probability that it is this humidity that either wholly or partially forms a sapid combination with the metal. Fabroni also made experiments with metals and water, from which he was convinced that chemical action took place. From the duration of this species of action, Fabroni supposed that it could not be electrical, because at that time electrical action was considered to be momentary only. Moreover, from the oxides and saline crystals which he obtained by a connected pair of dissimilar metals in liquids, he was led to the final conclusion, that to a chemical operation the whole phenomena are attributable.

Fabroni, however, did not think that by the contact of two metals the development of electricity was impossible; but he was decidedly of opinion that electricity was not the *primary* agent in producing the phenomena in the Sultzerian experiment. He was convinced, from his own experiments however, that metals have a reciprocal action on each other, and that it is this action which is productive of the phenomena at the time of their contact. This philosopher went even so far as to satisfy himself that this action gives a new power to the metals, enabling them to decompose chemical compounds, and to transfer their elements to new combinations; and he showed by a very simple experiment, that light is also developed by this species of chemical action.

Volta's views of metallic electricity induced him to prosecute his enquiries on the metals alone, independently of any connexion with the animal body; and by the assistance of his condenser, an instrument he had previously invented,* he was enabled to show that the mere contact of two dissimilar metals is sufficient to develope electric action appreciable by the

* For a description of the principles of the condenser, and the method of employing it, the reader is referred to my "Lectures on Electricity," page 46—48.

gold leaf electroscope. This discovery was the first grand result that Volta arrived at in the enquiry; and although he perverted its application by adducing it as a proof of the erroneousness of Galvani's hypothesis of animal electricity, he was eventually led to turn it to account in the most efficient manner in the construction of the pile which so justly bears his name. By this happy discovery, Volta has put into the hands of philosophers the most valuable electrical apparatus they ever yet possessed.

Volta's pile was first made known in this country in the year 1800. Its discovery consummated a long and successful career of enquiries which its author had closely pursued, and marked a new era in electrical science. Under the various modifications that the pile has since received, it has been the means of revealing to philosophers new and highly interesting classes of facts, and of establishing novel branches of study of the highest importance in experimental science. The activity of the pile, Volta, for a long time contended, was attributable to the electricity of the metals. Finding, however, that non-metallic bodies could be rendered available in the formation of the pile, he eventually relaxed the rigidity of his theory: but although, whilst thus modifying his theoretical views, he *indirectly* sanctioned Galvani's hypothesis, he never directly and openly acknowledged its correctness; but, on the contrary, when Doctor Valli had shown that by merely bringing a muscle and a nerve into contact with each other, the convulsive motions were still produced, Volta turned this fact to his own account, and vauntingly replied that, in order to render Valli's experiment successful, two things were essentially necessary. The organs of the animal brought into contact should be of dissimilar kinds, and that a third substance should intervene between them.

This attempt to explain away the hypothesis of Galvani, although lauded by many philosophers from that time to the present, was as strong a proof as the

Pavian Professor could have given of its correctness, for by this mode of explanation, the muscles and nerves are acknowledged to be in different electric conditions, which was the grand principle in the doctrine of animal electricity. As to the intervening medium between these organs, which Volta considered essential to the effect, the idea arose from Creve's and Fabroni's associations of metals and water, and from which he was so happily led to the formation of the pile, which is neither more nor less than a series of similar associations of metals and liquids, properly arranged for accomplishing concert of action.

LECTURE II.

Having pourtrayed an historical sketch of the progress of Galvanism for the first ten years of its cultivation, I will now endeavour to illustrate the various facts that were developed, by a series of experiments, which will lead you gradually from the simplest case of Galvanic action to those which appear more complicated ; and eventually to some of the most magnificent displays of electricity that have hitherto been produced.

In speaking of electricity in this place, it may be necessary to state before proceeding further, that electricity is divided into several distinct branches, and that Galvanism is one of them ; hence it is, that instead of the word *Galvanism*, we frequently say, *Galvanic Electricity*, which implies the same thing. The term *Galvanism*, was first applied to this branch of science in honour of Professor Galvani, who first cultivated it through a long series of experimental enquiries, before he made it known beyond the circle of his own friends. We also employ the term *Voltaism*, and *Voltaic Electricity*, in honour of Professor Volta, who was the inventor of the *Voltaic*

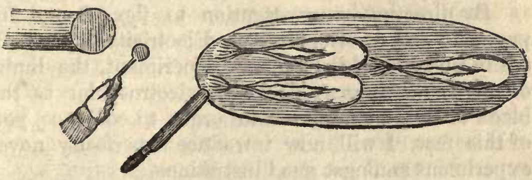
pile, an instrument which, in its various forms, is extensively employed in many interesting researches, and has been the means of developing more important facts than any other piece of electrical apparatus. It has even created new branches of science, for electro-chemistry and electro-magnetism owe their existence to its wonderful powers.

In proceeding with our experimental illustrations it will be as well, in the first place, to operate with apparatus as similar to those originally used as we can get them prepared, and employ them in the same manner as they were employed by their respective authors. By these means an opportunity will be afforded for obtaining a more perfect idea of the progressive steps by which Galvanism made its first advances, than by any other mode of illustration. I shall, however, in many parts of these lectures, introduce various pieces of apparatus of a very different construction to those which were first employed, and, occasionally, novel modes of experimenting will be resorted to. When I have passed through the necessary series of experiments for illustrating the discoveries during the *first period* of Galvanism, or up to the year 1800, when the Voltaic pile was first made known in this country, I shall no longer observe the chronological order by which the subsequent facts were discovered, but proceed by that route which appears to me most likely to develope the principles by which Galvanic phenomena are displayed, and those upon which the science is based, in the most simple manner.

When frogs are used as an article of diet, it is only the thighs which are thought to be sufficiently delicate for this purpose ; and, consequently, it was on these parts of the animal alone that Madame Galvani's discovery was made. This fact having begun a new era in electricity, it is usually, and indeed very properly, resorted to as the first step in experimental illustrations in this beautiful and interesting field of science.

In fig. 1, you will see that I have placed the hind legs of some skinned frogs on a plate, and have reared against the edge of the plate the blade of a knife, at a considerable distance from the prime conductor of an electrical machine. When the machine is in motion I will take sparks from the prime conductor to the brass ball which I hold in my hand;

Fig. 1.



and you will observe these limbs of the frogs convulsed at the precise time that a spark strikes the ball; although the latter has no connexion whatever with the knife or the frog's limbs.

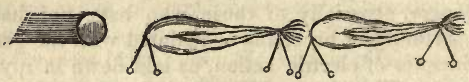
At first sight this fact appears to be involved in mystery, especially to those who have not had an opportunity of becoming acquainted with the general principles of electric action, as laid down in my lectures on Electricity; but when I refer you to the doctrine of electro-polarization, as explained in the fourth, fifth, and sixth lectures of that course, you will easily understand that the blade of the knife becomes polar by the electric action of the prime conductor, prior to its delivering a spark to the ball which I hold in my hand. Much of the fluid naturally belonging to the blade of the knife is also driven out at the farther extremity, by the superior electric pressure from the prime conductor, exerted on the nearest extremity of the blade: hence, it is not only electro-polar, but also *electro-negative*, so long as the prime conductor continues to be charged. But when I suddenly discharge the prime conductor by taking a spark to the ball which I hold in my hand, the electric pressure on the vicinal end of the

knife is suddenly lessened, and the latter immediately recovers its lost quantity of fluid from that body which, by vicinity and conducting character, is most suitably disposed to supply it. In the present case, this supply is from the limbs of the frog, nearest to the knife, which, though long detached from the rest of the animal, retains sufficient irritability, or sensitiveness, to become convulsed by each of these momentary discharges.

By directing your attention to figs. 6 and 26, pages 36 and 81 (lectures on Electricity), you will easily understand that in this experiment, the limbs of the frog became as decidedly electro-polar as the blade of the knife. And in order to convince you of this fact, I will now introduce a perfectly novel experiment amongst our illustrations.

I have here arranged the hind limbs of three frogs in nearly the same right line with the axis of the prime conductor of the machine. They are

Fig. 2.



insulated from one another, and also from the table, by resting on small slips, or tables, of varnished glass, which are supported on glass stems. I also hang from each pair of limbs, two pair of pith balls, as represented by fig. 2. When the machine is put into action, a divergency takes place in every pair of the electrosopic balls, which, by testing in the usual way, are found to be *negative* and *positive* alternately, in precisely the same manner as if suspended from the extremity of a series of metallic wires when exposed to a similar electric influence (see Electricity, fig. 6, page 36); and, consequently, each pair of limbs is polar, being negative in those extremities which are directed towards the prime conductor, and positive at the remote extremities.

Whilst the frogs are thus arranged I will take a few sparks from the prime conductor, and you will observe that every frog in the series is convulsed simultaneously with the passing sparks.

Our next business will be to show that this series of animals' limbs, whilst under the influence of the charged prime conductor, will display the electric star and pencil as distinctly as those phenomena are exhibited by polarized wires. For this purpose, however, the room must be rendered as dark as possible, in order that these faint electrical illuminations may become clearly distinguished.

Whilst on this theoretical topic, I will bring forward another experiment, which will show that, whilst under the influence of the electro-positive action of the prime conductor, the frog's limbs are rendered electro-negative. For this purpose I suspend the hind legs of a skinned frog by a silken thread, and hold it at some distance above the prime conductor of the machine, as represented by fig. 3. Whilst the machine is still in action, I remove the limbs of the frog to a distance, and place it on the cap of a Bennet's gold-leaf electrometer,* and I find that the leaves diverge with negative electric action. Hence we learn from this series of experimental illustration, that animal matter, in common with metals, is susceptible of electro-polarization and elecro-negation, when subjected to different degrees of electric pressure on the two opposite parts of its surface : and upon the same principle animal matter, whether a whole animal body, or only a detached part, would become electro-positive by being placed in the vicinity of the *negative* conductor ; for in that

Fig. 3.

* This instrument is described at page 42, &c., in the volume on "Electricity."

situation the animal would become electro-polar, by lessening the electric pressure on that particular side next to the conductor, and the remote side being thus rendered electro-negative, would present an opportunity for the introduction of fluid from the surrounding air.

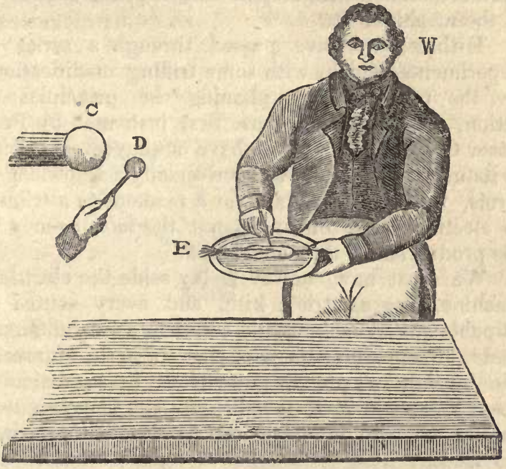
Another method of showing the electro-polarization of the animal body, is by placing a person on the electrical stool, with both arms stretched out as far from one another as possible, and holding in each hand a pith ball electroscope. In this position one hand is to be directed towards the prime conductor of a machine, and the other in the opposite direction. The moment that the machine is put into action both pairs of balls diverge; and by testing them by either excited glass or sealing-wax, that pair of balls nearest to the prime conductor is found to be electro-negative, and the more remote pair electro-positive. The two hands are therefore in different electric states, and, consequently, the arms are electro-polar.

If, whilst this person is in the electro-polar state, I present a large brass ball to any part of his body, the remote electroscopic balls will lessen their divergency; they sometimes collapse and fall together, whilst the negative balls, or those nearest the machine, will diverge further than before. These changes are occasioned by lessening the electric pressure on that part of the body towards which the ball is presented, which causes an accumulation of the electric fluid at that place to a greater extent than at any other part of the body, and at the same time increases the facility for the fluid to retire from that hand and arm which are directed towards the prime conductor. If the ball approaches the body sufficiently near to receive a spark, the whole body will be rendered electro-negative.

When an assistant is at hand, the effects of *secondary* electric action on the animal system are shown in a very elegant manner, by the arrangement

represented by fig. 4. The principal operator, W, holds in one hand a flat porcelain dish, on which is stretched the hind limbs, E, of a skinned frog, and

Fig. 4.



in the other hand a metallic wire. The thumb of that hand which holds the dish is placed upon the crural nerves of the frog, and the point of the wire held in the other hand rests upon the thick part of the thighs, whilst its upper end is slightly inclined towards the prime conductor, C, of an electric machine. Whilst thus arranged, the assistant takes a spark from the conductor to the ball, D, and the limbs of the frog are instantly convulsed. A series of sparks received by the ball, D, are productive of contemporaneous *secondary* electric movements in the wire, the operator's hands, and the limbs of the frog, which cause corresponding convulsive motions in the latter, in a very remarkable manner.

If, instead of the electrical machine, we were to employ an electrical kite, at a time when the air

would yield a good supply of fluid, the whole of the experiments already offered to your notice might be easily repeated, by arranging the apparatus in a similar manner, with respect to the reservoir (fig. 79, page 185, " Lectures on Electricity"), as hitherto has been done, with respect to the prime conductor of the machine.

Hitherto we have passed through a series of experiments, which, with some trifling modifications for the purpose of explaining the principles of action, are similar to those first instituted by Professor Galvani; and as we have employed electricity in its most indisputable and universally acknowledged forms, we cannot hesitate for a moment to attribute to electricity the CHIEF, if not the *sole*, agency in the production of the phenomena.

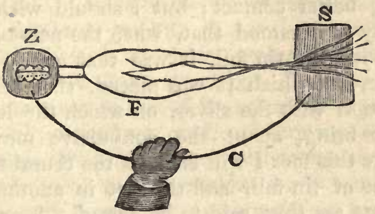
We must now, however, lay aside the electrical machine, the electrical kite, and every source of palpable electric action, and resort to a very different mode of experimenting to that hitherto pursued. We must now prepare our frogs in a particular manner, according to the directions of Galvani, and operate on them as first shown by that distinguished philosopher.

The preparation of the frogs is thus to be carried on. I take hold of the hind feet with my left hand, whilst an assistant takes hold of the fore feet; and, whilst the animal is thus stretched between us, I cut it in two with a pair of scissors, directly across its body, a little below the shoulders. The fore part of the body is thrown aside as useless, and the entrails cleared away from the other part, which is intended to be the subject of experiment. The skin being partially cleared from the upper part of the remaining spine, my assistant takes hold of the latter between his thumb and fore finger, holding it fast till I have stripped the whole of the skin from the thighs and legs. The crural nerves, which are two bundles of white silken-like cords, parallel to one another, are now to be cleared of all fleshy matter, and from the

bones which are behind them, so as to be free from every other part but the thighs, and a morsel of the spine, which I leave attached at their superior extremities.

Thus prepared, I place the morsel of spine upon a piece of zinc, z, and the feet upon a piece of silver, s, as represented by fig. 5. With this arrangement the

Fig. 5.



limbs remain perfectly motionless. I now, by means of a copper or silver wire, c, make a connexion between the silver and zinc, at which moment the thighs, F, and the whole of the lower extremities, are thrown into violent agitation, quivering and stretching themselves lengthwise, in a manner too singular for language to describe. If, however, I keep the wire in close contact with the silver and the zinc, the phenomena exhibited by the frog's limbs are but of momentary duration; but they are again renewed when the wire, c, is withdrawn. Thus it is, that by keeping one end of the wire in close contact with either the silver or the zinc, and moving the other end rapidly so as to make a series of momentary contacts with the other metal, the limbs may be kept in a state of continuous agitation.

The wire, c, when thus employed, is called the *conducting arc;* and the whole arrangement, when the wire unites the other two metals, as represented in fig. 5, is called a *Galvanic circle.* When either end of the conducting arc, c, is lifted up so as to quit the metal on which it rested, the circuit, or

circle, is said to be *opened*, and a renewal of the contact *closes* the circle ; hence, in Galvanic language, the frog, in the last described experiment, is agitated by a series of alternate *openings* and *closings* of the Galvanic circuit.

For some time after Galvani had discovered these extraordinary facts, it was the practice to fold the crural nerves and morsel of spine in a piece of tin foil, for no other purpose, it was said, than that of securing better contact; but I should wish it to be distinctly understood that, when the nerves were so armed with the tin foil, it was that metal, and *not* the zinc, on which it was placed, that tended, in conjunction with the silver, on which the legs were laid, to bring about the convulsive movements. To prove this fact I will enclose the crural nerves in one piece of tin foil, and the feet in another piece ; both parts are thus said to be *armed*. I now place one of these *armed* parts upon a piece of sheet zinc, and the other upon a half-crown, taking care that no part of the animal touch either of these metals. I now close the circuit by a conducting arc, but no motions of the animal are perceptible. I open and shut the circuit rapidly for many times, but still the usual phenomena do not appear. If, however, the limbs had been those of a healthy vigorous frog, and the experiment carried on immediately after their removal from the body, some slight agitation would have taken place by this mode of proceeding; but the subject now operated on is too feeble, and too much exhausted of its irritability, to be affected by it.

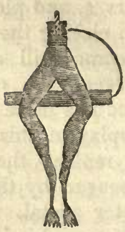
Having now satisfied ourselves that the animal's powers are too dormant to be awakened by this mode of experimenting, I will remove the tin foil from the feet, and place them upon the bare silver coin. Under these circumstances, we soon discover that the dormant animal powers are aroused into a state of great activity whenever the circuit is completed by the conducting arc. To vary the experiment

once more, I remove the tin foil from the crural nerves, and place them naked upon the zinc plate. On closing the circuit now, the convulsive struggles become still more violent than when the crural nerves were encased in the tin foil; proving that zinc is a more suitable metal than tin foil for the display of this class of phenomena: and if we were to replace the silver by tin foil, we should soon discover, by the same criterion, the inferiority of the latter metal. It is thus by experimenting with different kinds of metal, that we are enabled to understand which two, when acting in concert, are productive of the greatest effect. Zinc has hitherto held a supremacy as one of the metals in experiments of this kind; and silver, gold, or platinum, the other. Copper and zinc answer very well in the capacity of a *Galvanic pair*, as the combination is termed, and copper is more frequently employed than any of the noble metals.

In the experiments on frogs by a *Galvanic pair* of metals, it is not necessary to place the feet upon the silver, and the crural nerves upon the zinc; for the convulsive motions will be produced when the animal is placed on these metals in the reverse order, that is, with the feet upon the zinc and the nerves upon the silver. Nor is it of much consequence which metal is employed for the conducting arc. Indeed, a metallic wire is not absolutely necessary for this purpose; for charcoal, or even water, as I shall presently show you, will answer very well for the conducting arc: and I will now show you, that a morsel of charcoal may substitute even the silver in the formation of a *Galvanic pair*.

The experiment I am now about to introduce, will explain several particulars in performances of this kind; it is, therefore, highly instructive to an attentive observer. I tie, by means of thread, a small piece of charcoal to the spine of a prepared frog, and upon a slip of zinc, to which one end of a metallic wire is soldered, I place the thighs of the

Fig. 6.



animal, as represented by fig. 6. I now take hold of the wire, and complete the circuit by bringing its loose end into contact with the charcoal, and immediately the animal is convulsed; and, as in previously shown experiments, it is again convulsed when the circuit is opened.

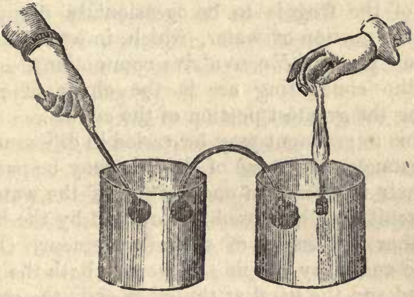
In this case, it is proved that charcoal answers all the purposes of silver in experiments of this kind; and also, that it is not necessary that the *feet* should rest on one of the elements of the Galvanic pair; which is still further proved, if necessary, by cutting them off, and operating on the remaining parts only. And another variation of the experiment shows, that the convulsive motions can be produced by operating on the exterior muscles only, and thus dispensing with the crural nerves. If, for instance, I remove the crural nerves by scissors, and place the thick part of the thighs upon a piece of zinc, and the feet upon a half-crown, neither metal will be in *direct* contact with the nerves. Still, however, it will be found, on completing the circuit with the conducting arc, that the usual phenomena are produced, though in a minor degree.

If, whilst using the zinc and charcoal, as represented by fig. 6, we permit the two to be firmly united by the conducting wire, we may open and shut the circuit by lifting the frog's thighs from the zinc, and again bringing them into contact with that metal. The limbs are agitated as decidedly by this operation, as when the circuit is opened and closed by the conducting wire. Indeed, it is a matter of no consequence in what part of the circuit the opening be made, the effect is still the same; but as the apparent struggles of the animal are best shown when the limbs are quite free to move, the most commodious mode of operating is, by employing the wire for opening and closing the circuit. There is

also another particular to be observed when the best effect is required. This is the bending of the knees of the frog so as to draw the feet up to the thick part of the thighs, when placed on one of the metals ; for as there is always a tendency to stretch or throw the legs outwards in the direction of their length, when the circuit is closing, these motions are best shown when the limbs are previously bent in the manner described.

I will now bring forward a few experiments which will inform you that to *Galvanize* the limbs of a frog, a metallic contact with it is not absolutely necessary. Fig. 7 will give an idea of the apparatus I shall first employ in this illustration. The two

Fig. 7.



small jars, which may be either of glass or of porcelain, are nearly filled with water. The two portions of water are connected with each other by a metallic arc, having a piece of zinc soldered to one end and a small silver coin to the other, as represented by the figure. I take hold of the feet of a prepared frog with the finger and thumb of one hand, and in the other hand I hold a metallic wire. Thus prepared, I dip the morsel of spine, which hangs by the crural nerves, into the water of one of the vessels, and close the circuit by touching the other piece of water with the wire. The frog is strongly convulsed at

every contact that is made between the water and the wire. If I permit the wire to remain immersed, and occasionally open and close the circuit by alternately lifting and dipping the frog from, and into, the water, the phenomena produced are precisely the same by this process as by the other.

The experiment is pleasingly and instructively varied, by having a circuit of several persons between the limbs of the frog and the water in the vessel. Suppose, for instance, eight or ten persons join hands, so as to form a chain from one end to the other. The disengaged hand of one of the extremities of the chain, or range of persons, is to take hold of the legs of the frog, and the disengaged hand at the other extremity of the range, is to be immersed in one portion of the water. This done, the pendent spine of the frog is to be occasionally dipped into the other portion of water, which, in every case, will occasion the usual convulsive commotions. In this case the conducting arc is the chain of persons forming the greatest portion of the circuit.

This experiment may be varied in different ways. For instance, the spine of the frog may be permitted to remain immersed in one portion of the water, and the circuit may be closed and opened by the hand at the other extremity of the arrangement. It may also be varied by keeping immersed both the frog at one end and the hand at the other end, the openings and closings being accomplished by any two adjoining hands in the arrangement. But the most singular effect is produced by holding the spine in the hand, and permitting the pendent toes of the frog to just touch the surface of the water, the remaining part of the circuit being previously completed. By this simple immersion of the limbs, the most singular antick motions are exhibited by them. The toes are thrown out of the water at the first contact, which opens the circuit; they immediately fall down again and close it, at which moment they are again convulsed and thrown out, and again the circuit is

broken. They again fall down, and are again thrown out; and thus the action may be kept up for half an hour, or longer, if required, a dance by the detached limbs of the frog being performed all the while, to the no small amusement of the spectators.

If, instead of having so long a circuit, which always weakens electric action, there were but one person engaged in the experiment, immersing one of his hands in one portion of the water, and with his other hand taking hold of the crural nerves, the *frog steps* are displayed, on the aqueous stage, in a first rate style, and especially when the experiment is made on the limbs of a vigourous frog, and immediately after their being detached from the body. In all cases where the hands form a part of the circuit, they ought to be well moistened with water, to increase the conduction of the skin. By paying attention to this particular, the electric action meets with less obstruction, and the animal commotions are more eminently displayed.

The next experiment which I shall offer to your notice requires nice electrical discrimination to understand it: and, of course, it will require all the attention you can afford to give it that degree of interest which it really deserves. Having an already prepared frog, I hold it by the crural nerves in one hand, and permit the limbs to hang pendent over a small plate of zinc which is placed on the table; and by permitting the toes to touch the zinc plate you will behold the most singular *frog's hornpipe* you ever witnessed. But what can be the cause? You see only one metal, and no Galvanic circuit! In all our former experiments a circuit could easily be seen; and permit me to tell you, that no animal commotions by Galvanism can possibly be produced independently of a complete circle of conductors. Therefore, although the circuit in this case is not so palpable as in our previous experiments, the phenomena that you have witnessed are sure indications of its existence; and as these experiments are intended

to teach, and not to mystify, I will now let you into the secret of the arrangement, by which means you will as easily trace a Galvanic circuit in this case as in any other.

If you will have the goodness to remove the zinc plate, and examine the spot where it laid, you will perceive the head of one of the nails which holds the top of this old table to its frame. Now this nail being in contact with the zinc whilst the experiment was carrying on, you can have no difficulty in discerning a Galvanic *pair* of metals; and by considering that the table is not an *insulator*, though a very bad conductor, it serves to form a part of the conducting arc. The floor also which lies between the foot of the table and my boots, forms another part of the circuit. Then, since you are well aware that the human body is a good conductor, and that the soles of my boots conduct partially, you are easily led to admit, that the circuit was complete whenever the frog's toes touched the zinc plate, and that it was opened every time they sprang from it.

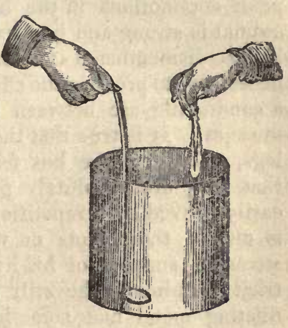
To convince you that the circuit was in the direction I have pointed out, we will repeat the experiment, and afterwards slightly vary it. Being satisfied that the frog dances as before by the same arrangement, I will now step on a resinous cake, and the dancing immediately ceases; because the resinous cake insulates me from the floor, and prevents the circuit from being closed. But if, whilst standing with one foot on the resin, I touch the floor with the toe of my other boot, the circuit again becomes closed, and the dancing frog resumes its hornpipe. To a perfect stranger, these performances, when the process is concealed, have a truly magical appearance. The illusion, however, is much more perfect, even sufficiently so as to puzzle a moderately skilled Electrician, when the zinc plate has no nail in contact with it. Old kitchen tables are sometimes burnt in various places on the upper surface, and when a piece of bright zinc is laid upon one of these

burnt spots, a Galvanic pair is formed between the metal and the charcoal, which produces more violent commotions in the animal's limbs, than by the iron nail and the zinc.

When the zinc is touched by a piece of silver or copper, held in the other hand, the circuit is shortened, and the Galvanic pair of metals more active than the zinc and iron; hence, on both these accounts, the dance is much more animated than by the other mode of experimenting. If the muscles of the thighs are separated so as to hang together by no other tie than the nerves and spine, the commotions are still as active as before. Indeed, a single limb, entirely removed from the other, performs its steps in a very animated manner.

When the legs are cut from a very lively and vigorous frog, the commotions are produced independently of any *direct* contact of the metallic elements of the Galvanic pair. If, for example, a piece of zinc be let fall to the bottom of a tumbler of water, and the feet of a prepared frog held in one hand, and a copper or a silver wire in the other, as represented by fig. 8, and the crural nerves of the animal be immersed in the water, then, as soon as the metallic wire touches another part of the water, a circuit is formed, which has the power of agitating the pendent limbs. This effect, however, is comparatively slight; but another action is produced, more violent than the former, by pressing down the wire until it touches the zinc. The frog is now strongly convulsed. To give the best effect in this experiment, the hands of the operator ought to be well moistened

Fig. 8.



either with simple water, or with a solution of common salt, which is still better ; and if the vessel contain a solution of salt (muriate of soda) instead of water, the action is much enhanced.

There is something very beautiful and instructive in this experiment. The first part of it shows that a Galvanic circuit can be formed independently of any *direct* contact of the metals forming the pair ; and the latter part teaches us to understand that, although the metals are surrounded by the water, which is a good conductor, and which consequently forms a distinct circle with the metals when brought into contact, yet another circle is formed through the operator and the frog.

LECTURE III.

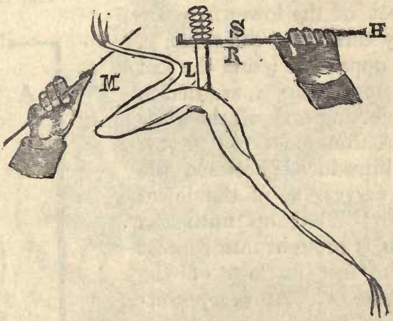
Hitherto our experiments have been performed by means of two dissimilar metals, or of one metal and charcoal, which formed what is called the Galvanic pair ; but it was shown by Galvani, that the presence of two metals is not absolutely necessary to accomplish commotions in the limbs of a frog, when the animal is strong and in a lively condition, prior to its being dismembered for experiment. It is only necessary, to produce the effect, that a silver wire form a conducting arc between the crural nerves and the muscles. It is true that the twitchings of the thighs, legs, and toes, are but feeble by this process ; but that they are absolutely produced is a fact which is easily proved by a repetition of the experiment. It is one of those facts on which Galvani laid great stress in support of his hypothesis of animal electricity, although he still suspected that the conducting metal had some influence in producing the effect.

Galvani, hawever, proposed several methods of experimenting, independently of the aid of metals ;

and the experiment now about to be described, shows in the most satisfactory manner, that neither metals, charcoal, nor any intervening body whatever, is absolutely requisite to convulse the limbs of a prepared frog. It is an experiment first instituted by Professor Aldini, the nephew of Galvani, and shown at the Institute of Bologna, in the year 1794.*

Fig. 9 will afford a good idea of the method of making this experiment. The frog is held up by a

Fig. 9.



glass rod, H, which passes between the crural nerves, R, attached to a morsel of the spine, S. By means of another glass rod, M, one of the legs is so managed as to bring the joint, L, into contact with the crural nerves; and, by this simple process, the limbs become convulsed. To insure success in this delicate experiment, it is well to immerse the whole of the limbs and nerves in a solution of common salt (muriate of soda), previously to making the experiment. The animal's motions are very slight, but sufficiently decisive to show the fact.

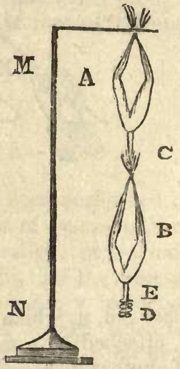
There can be no doubt entertained, but that an electric action from the metals, when employed, operates extensively in the production of those violent struggles which the animal displays; but in the

* Aldini's work, p. 17.

experiment last described, no metal being employed, and the animal completely insulated by means of the glass rods, the convulsive movements were obviously due to an electric action emanating from the animal alone.

The effects on animals, due to a commotion or discharge of their own electric fluid, from one part of the system to another, is still more satisfactorily shown by a series of prepared frogs, as represented by fig. 10. In this figure, M N is a bent glass rod, and A B two prepared frogs. The feet of the lower frog are tied, by thread, to the spine, C, of the upper one; and the feet of the upper frog, A, are tied to the projecting arm of the glass rod. A thin glass rod is now to be introduced between the crural nerves, E, of the lower frog, and lifted up until the spine, D, is brought into contact with the feet or legs of the upper frog, A. At every contact, both frogs are convulsed. I have produced a similar effect by a chain of six frogs, the whole of which were convulsed whenever the contact between the spine, D, and the legs, A, of the upper frog, was completed.

Fig. 10.



Aldini, who was ever anxious to support the views of his uncle, prosecuted his enquiries on animal electricity with much vigilance and care, and produced many striking effects by operating on recently killed animals only, independently of the employment of any metal in his experiments. The two following experiments were successfully performed by this indefatigable physiologist. They are experiments I have never had an opportunity of repeating; but the arrangements are so judiciously chosen, that there can be no doubt of satisfactory results being obtained.

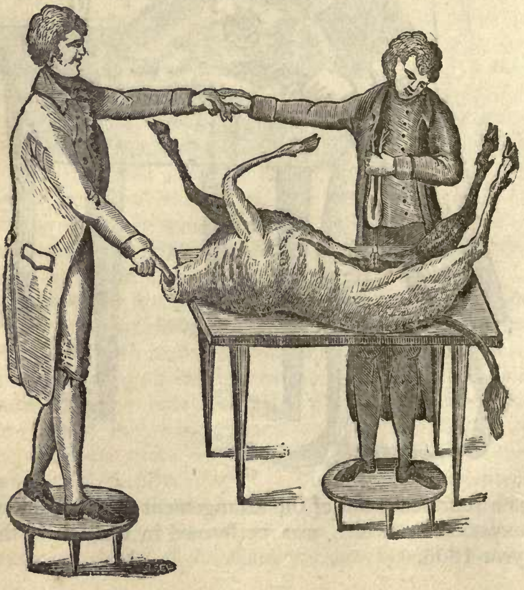
Having provided the head of an ox, recently killed, Aldini pushed a finger of one of his hands, well moistened in a solution of common salt, into one of its ears. The spine of a prepared frog, which he held by the feet in the other hand, was then made to touch the upper part of the tongue; convulsive motions in the frog were immediately produced, and were repeated whenever the contact was made between the frog and the tongue of the ox. Fig. 11

Fig. 11.

is a representation of the arrangement in this famous experiment, which was performed in London in the year 1803.

The next described experiment, also Aldini's, is similar to the former, the only difference being in the length of the circuit. Having placed the trunk of a decapitated calf on an insulated table, a longitudinal incision was made in the breast, for the purpose of exposing a long series of muscles. Aldini then arranged two insulated persons in such a manner, that the one with a finger, well moistened in a solution of common salt, touched the spinal marrow of the calf, whilst the other applied the morsel of spine, hanging by the crural nerves of a prepared frog, to the muscles of the trunk. The disengaged hands of the two persons being previously moistened in the salt solution to improve the conduction of the skin, the circuit was closed by uniting them in the manner represented by fig. 12, which is also a

Fig. 12.



representation of the whole arrangement. Every time this circuit was closed, the frog was strongly convulsed; but no commotion occurred by simply touching the muscles of the calf with the spine of the frog, when the outer hands of the operators were not united.

These highly interesting experiments can be repeated under those circumstances only in which the larger animals employed can be had as soon as killed. Aldini had many opportunities of experimenting on the bodies of decapitated criminals, and made several successful inquiries of this kind, by employing the human body in the same manner as the trunk of the calf in the last described experiment.

The same sagacious physiologist made several other experiments in animal electricity, which can be easily repeated by any one who can command a frog of strong vital power. The frog is to be prepared in the usual way, and, after moistening it in salt water, the operator takes hold of the legs, and brings the crural nerves to his own tongue. The Galvanic circuit, in this case, is through the frog and the operator, from the hand to the tongue. The usual commotions are produced at every contact between the nerves and the tongue.

If several persons form a chain amongst themselves by joining hands, well moistened in salt water, and that the person at one of the extremities of the chain hold the legs of a prepared frog, contractions are produced whenever the circuit is closed by the disengaged hand, at the other end of the chain, and the crural nerves of the frog. Many persons have failed in repeating these experiments, from their not operating on large frogs of great activity; and others by not attending strictly to the necessary preparations.

The experimental illustrations hitherto brought forward in these lectures, would, of themselves, be sufficient evidence to convince most physiological enquirers, who have no preconceived notions to support, that in the animal frame the different organisms

of which it is constituted, are naturally charged with the electric fluid in different degrees of *density*, or *intensity*, as we frequently express ourselves ; as, for instance, the nerves and muscles have each a natural charge peculiar to itself, and in accordance with its susceptibility ; for the susceptibilities of becoming electrically charged, differ considerably in bodies of different kinds, indeed in those of the same kind, when differing in structure. Hence, since the organization of muscle and nerve differ from each other, so must their natural electric charges differ also.

But the most palpable cases of animal electric action are those displayed by the Torpedo, and the electrical Eels, which are endowed with such formidable electric powers as to destroy other fishes by their discharges, which they seem capable of delivering at their own will. It is thus that they procure their prey amongst the smaller tribes of fishes, and probably parry off their enemies amongst the larger ones, which otherwise, from their size and voracity, might devour them in abundance.

I will not, however, interrupt the regular train of our elementary experimental illustrations, by a description of the electric organs of these remarkable fishes, in this place ;* nor will I dwell longer on animal electric action, since the experiments we have passed through afford a sufficient type of all that has been done in this department of our subject. There can be no doubt that, besides the electric action due to those animals which have been operated on, the sensitiveness of those parts of the frog employed in the experiments, render them exceedingly useful in the capacity of electroscopes, the convulsive motions of which were the only indications of electric action.

The tongue, however, is an organ whose susceptibility of delicate electric impressions fits it admirably as an electroscopic apparatus in certain enquiries

* These particulars will be found in the Appendix.

in this branch of physics. The experiment of Sultzer, already named in our first lecture, is probably the first on record in which the tongue was intentionally employed as an indicator of a peculiar development now well known to be electrical. This experiment, and those variations of it by Creve and Fabroni, as pursued by Volta, Cruickshanks, Davy, and others, have been the means of throwing much light on chemical action, and affording more rational views of many processes of nature than those previously taken.

To proceed with this experiment in the most efficient manner, a plate of bright sheet zinc, and a similar plate of silver, gold, or platinum, ought to be employed: the one covering a portion of the upper part of the tongue, and the other the lower part, having their outer edges projecting so as to be conveniently held by the hands. Whilst the outer edges of the plates remain separate, no peculiar sensation is experienced; but the moment that these edges are brought into contact with each other, the tongue is made to quiver, and a disagreeable acid taste is produced. The quivering of the tongue is but of momentary duration, if the metals be kept close together; but the acidity in the mouth increases as the period of contact is prolonged.

On making the metallic contact, a sudden flash of light sometimes darts across the eyes; and as this phenomenon is best observed when the eyes are closed, the flash obviously passes *through* some part of the organ of vision. But the flash of light is most successfully produced, when one of the metals is placed on the tongue, and the other pressed close upon the gums beneath the upper lip. With this arrangement, the flash is constantly produced at the moment of contact of the outer edges of the metals. In both these experiments, the effects produced are greater as the surfaces of the metals exposed to the tongue are increased; and if that organ were to be bathed in salt water the moment before the metals

are applied, the effects would be still greater. A draught of porter considerably enhances the effects.

The experiments of Messrs. Creve and Fabroni are those which next require our attention. The inquiries of these two philosophers were chiefly directed to the *cause* of Galvanic phenomena, which the few experiments that they instituted, led both of them to imagine was of a chemical nature. If a slip of zinc, and another of copper, silver, gold, or platinum, be placed in a sloping position in a glass vessel nearly filled with water, in the manner represented by fig. 13, and if now the tongue be applied to any part of the surface of the water between the metals, nothing particular is observed; but if whilst the tongue is still immersed, the lower edges of the plates be made to touch one another, an acrid taste is immediately produced. This is an interesting variation of the Sultzerian experiment; for it teaches us that metallic contact with the tongue is not absolutely necessary to produce the peculiar sensation in that organ, which, in this case, as in the original experiment, is the *electroscope*. The effect on the tongue, however, is far more feeble than that produced by the original experiment of Sultzer.

Fig. 13.

This experiment is susceptible of other interesting variations. When the vessel holding the water is somewhat large—a glass basin, for instance—the tongue may be immersed at different distances from either of the metals, whilst they remain in contact with each other. When the tongue is about half-way between the metals, the effect is scarcely perceptible, but becomes stronger as it approaches either of them. Moreover, the acrid taste is experienced, although the tongue be immersed in any other part of the water than that which lies *directly* between the metals, which shows that the influence occupies every part of it. This latter fact was not noticed by

the above named philosophers, nor did they give any satisfactory reason for the effect being greatest near the metals. From some chemical effects which Fabroni observed, he supposed every Galvanic phenomenon to have a chemical origin. This sagacious philosopher discovered that the zinc was always oxidized in these experiments, and consequently, that the water was decomposed; and by employing solutions of various kinds of salts, he was enabled to form new compounds in crystallized forms. To Fabroni, therefore, the honour is due of making the first electro-chemical discovery, and of inventing the chemical hypothesis of Galvanism, which, even at this day, is the favourite phantom of certain chemists, both in this country and on the continent. Moreover, as Fabroni's experiment is the first in which a Galvanic pair of metals were associated by means of inorganic matter—an association which constitutes one complete member of the Galvanic battery, which now universally bears that name—the invention of that noble instrument necessarily dawned with Fabroni's experiments, and its history is to be traced to the admirable researches of that philosopher.

To repeat this memorable experiment in the most satisfactory manner, we place a piece of very clean zinc at the bottom of a glass of water, and upon the zinc is to rest a slip of very clean copper, or silver. In the course of a few minutes, or a quarter of an hour, the zinc around the point of contact with the other metal will become blackened, and by permitting the action to continue uninterruptedly for several hours, the whole of the upper surface of the zinc will become covered with the black matter, which is a thin layer of the oxide of zinc. On inspecting the copper before the apparatus is disturbed, its surface will be found covered with exceedingly minute bubbles of gas, which is hydrogen. If the slip of copper has an *edge* resting on the zinc, a line of black matter (oxide of zinc), directly under it, will be formed in the course of a few minutes; and

as the copper can be curved in any way the experimenter thinks proper, devices of any required form may be obtained on the upper surface of the zinc. I have the word FABRONI formed on the lower edge of a slip of copper, by means of which I occasionally in my lectures, imprint the name of the author of this first of electro-decompositions of water by a *direct* Galvanic association of metals.

As it is not my intention to enter very minutely into the theory of Galvanism, until the next and subsequent lectures, I shall, in this place, offer to your notice only a few experiments from which Galvanic phenomena have been supposed to have an electric origin.

I have already stated that, in the Franklinean theory of electricity, it is supposed that each individual kind of matter has a *specific* quantity of the electric fluid naturally belonging to it, so that no two bodies of the same size, if of different kinds, contain equal quantities; which view of the natural distribution of the electric fluid amongst terrestrial bodies, appears to be perfectly correct, at least under certain circumstances. I shall, however, have to show you, as we proceed, that the distribution of electric matter, even in one individual body, may be, and more frequently than otherwise is, very different in different parts of it; depending on its state of aggregation, crystallization, compactness, state of its surface with regard to polish, temperature, &c.; and if it can be shown that different parts of the surface of one and the same piece of metal, which are attached to each other by the best conducting union, are nevertheless in different electric conditions at one and the same time, it is easy to imagine that two distinct kinds of matter may be in different electric conditions, even when in close contact with each other.

The experiment of Lichtenberg, already explained in my "Lectures on Electricity," shows this fact in a more striking and interesting manner than any with which I am acquainted; and as it is one of high

importance in preparing the mind for reasoning on the *modus operandi* of Galvanic action generally, I shall repeat it in this place. The apparatus required for the performance of this experiment are an electrical machine, a small Leyden jar, a flat cake of pitch, a small tin can with a glass stem for insulation, and a spring puff or bag, containing a mixture of sulphur and red lead.

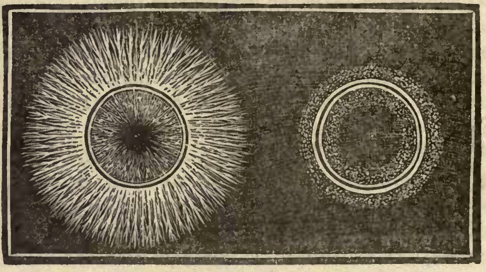
The resinous cake being quite dry and free from dust, I place the little can upon it at some short distance from the middle of the surface. I then electrize the inside of the jar *negatively*, either by placing its knob in connexion with the negative conductor of the machine, or by holding its outer coating against the prime conductor: (the former way is preferable, because the hand has already hold of the body of the jar) which done, I present its ball to the can, from which it recovers a small quantity of its lost fluid. The can, consequently, becomes *electro-negative*, and its rim in connexion with the resinous cake renders a ring of the latter also negative.

I now lift up the can by its glass handle, and for a moment touch it with my finger to restore its electric equilibrium. The can is then placed on another part of the resinous surface, the jar discharged, and again recharged with its ball at the prime conductor. A spark is now transmitted from the ball of the jar to the can, which renders it *electro-positive*; and a considerable portion of this charge is transmitted to the resinous cake, spreading outwards by its repulsive attribute, on every side of the can; and when the latter is removed by its glass handle, the electric fluid advances inwards also, until the forces on opposite sides of the centre, balance one another, and completely arrest the fluid's further advance.

The cake being thus differently electrized on two parts of its surface, is placed in a vertical position; and then standing at a considerable distance, I project towards it the mixed powers from the spring bag,

which, whilst traversing the air between the bag and the electrized surfaces, became influenced by the latter, and attracted by them, according to the strict principles of electric action: the sulphur attaching itself to the positive surface, and the red lead to the negative one. The beauty of this experiment is beyond all description, and, in a theoretical point of view, it is one of the highest importance. Fig. 14 will serve to

Fig. 14.



give an idea of the arrangement which the powders assume on their respective places on the resinous cake, but nothing short of a personal view of the phenomena can convey to the mind their real beauty and importance.

A momentary glance at these electrical pictures delights the eye, by the beauty and singularity of their configurations; and when it is known that they are of electrical production, the curiosity becomes quickly aroused, and the attention immediately fixed upon them. To the mind of the philosopher these phenomena convey a rich fund of information. Volumes have been written to show the similarity of positive and negative electric action, as indicated by the spark, the shock, the attractions, and the repulsions, &c,; and much has been said and written with a view of supporting the contrary opinion. But the experiment now under contemplation, carries conviction to the mind more forcibly than all the rest that have been brought forward on either side of the

question. The first view of these pictures is of itself sufficient to distinguish a striking difference in their configurations, and the mind is readily impressed with the idea that their formation arises from different causes. On close inspection, we perceive a seeming animation in the *positive* or stellar configuration, which expands before our eyes, gradually and uniformly on every side, until the repulsive electric forces become too attenuated to advance the particles of sulphur any further from the centre of action. Inward also from the ring on which the metallic can stood, the particles of sulphur are seen creeping in converging paths towards a centre which they can only approach, but can never reach, being arrested in their advance by a balance of those very forces which urged them on towards it.

The negative picture, on the contrary, is dull, without life, and a perfect contrast to the other, yet not without interest. It shows, in the first place, that it is not endued with any force similar to that in the other picture. No repulsive forces are indicated by the motions of the minutest particle of the powder; nor are any ramifications produced, even though the apparatus be permitted to rest unmolested for many hours; the picture remains unchanged from first to last, a mere heavy looking ring of red lead. Around this ring, however, at a considerable distance, and also within it, when its dimensions are considerable, there adheres a portion of the sulphur, whose subsequent motions, with regard to the centre, are in the reverse order to those in the positive picture; for the particles of sulphur *within* the ring radiate towards it *from* the centre, and those exterior to the ring travel inwards; hence both portions advance upon the ring of red lead, according to the laws of electrical attraction between two dissimilar electrized bodies. In short, the phenomena exhibited by this experiment afford the most satisfactory demonstration of the distinctive character and capabilities of these two specks on the resinous surface, and of the just

appropriation of the terms *positive* and *negative*, as expressive of their real electric states. On the *positive* surface, we have occular demonstration of the existence of a repulsive force ; on the *negative* surface there is no indication whatever of any such force being present. Moreover, we learn from this experiment that, although intimately connected with each other, the sulphur and red lead were in different electric conditions.

This fine experiment is susceptible of many variations, each of which is full of beauty and interest. Metallic forms of the outlines of animals, trees, houses, and other objects, may be employed in place of the can ; and these may be rendered positive or negative at pleasure, according to the fancy of the operator. Different kinds of powders may also be used for the formation of the pictures. When the different coloured lakes, pigments, and other impalpable powders are used, the pictures may be made exceedingly elegant ; and they may be rendered permanent, and framed, when formed on glass, wax, &c., which substances answer quite as well as pitch. When formed on glass, another piece of glass is placed upon the picture, which is thus held fast between the two. The wax, or other substance that will melt by a gentle heat, will easily adhere to the electrical pictures, by holding over them a hot iron, or by presenting them to a gentle fire. Many other methods might be pointed out which will readily occur to the ingenious electrician.

The Rev. Abraham Bennet was the first philosopher in this country who repeated Lichtenberg's experiment ;* and as it led him to others in which he discovered a difference in the natural electric conditions of

* The Rev. Abraham Bennet, when curate of Wirksworth, Derbyshire, diversified this experiment probably more than any other person. This is the same ingenious electrician who invented the gold-leaf electroscope. Many years previously, however, a similar electroscope, made of two narrow strips of tin foil, was used by Baccaria.

dissimilar metals, a knowledge of which is important in this place, I will point out the method of experimenting pursued by this philosopher. Into a small copper shovel, furnished with a glass handle, is put some coarse zinc filings, or other morsels of that metal; the shovel is then held over the cap of a gold-leaf electrometer, and the zinc filings permitted to roll out of it on to the cap. The gold leaves diverge with *positive* electric action. If now the shovel be tested by an electroscope, it will be found to be *electro-negative.* These metals still exhibit the same relative electric action, when the shovel is of zinc and the filings of copper, which proves that the mode by which the experiment is made does not interfere with the electric character which the metals acquire by their simple contact with each other; a fact which is still further supported by another mode of experimenting presently to be brought forward.

Some experimenters use a metallic sieve in place of the shovel, and shake the filings of the other metal through the sieve, so that they may fall on the cap of the electroscope. By a similar process, the electric character of any metal, acquired by contact with any other body, metallic or otherwise, may easily be ascertained.

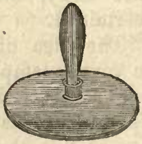
The idea of electric action being developed by the metals employed in his experiments, seems to have originated with Galvani himself; and the experiments last described, have shown the correctness of this theoretical view. This principle now enters essentially into the theory of Galvanism; so far at least as the metals are concerned in the development of Galvanic action. But the original experiment of Lichtenburg proves also that other bodies than metals develope electric action by mere contact with one another; and as Galvanic arrangements are never entirely of metallic matter, but consist partly of metallic and partly of non-metallic bodies, the electric actions of all the bodies which enter into a Galvanic circle are essentially concerned,

either *directly* or *indirectly*, in producing the resultant or principal effect. In all the Galvanic experiments hitherto described, in which metals were employed, those bodies had obviously a predominant influence over the other matter which entered the circle; and what is to be particularly remarked is, that through the instrumentality of the *animal electroscope* (prepared frog), we are enabled to detect the action thus displayed, independently of the ordinary means of insulation.

LECTURE IV.

VOLTA, who had studied the electricity of the metals with great assiduity and success, brought forward, in the year 1800, his interesting experiment with the metallic discs, which still bear his name. The Voltaic discs are of copper and zinc, one of each, and usually of about six inches diameter. Each disc is furnished with a glass handle, as represented by fig. 15, for the purpose of insulation from the hands of the operator. The other face of each disc is perfectly flat and polished, to insure as extensive contact as possible, when those faces are brought together.

Fig. 15.

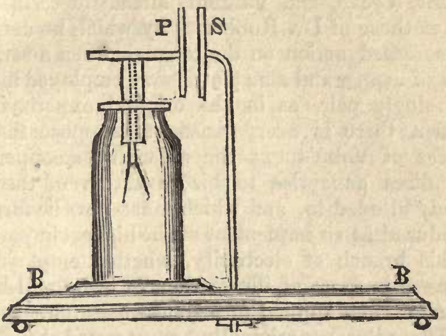


As the electric action developed by these discs is exceedingly feeble, when compared to that shown with the metallic filings in Bennet's experiments, it is usual to employ a condenser in connexion with the electroscope, in order to obtain satisfactory results. The electroscope, with its condenser, is represented by fig. 16.* Before the experiment is performed,

* To those who have read my "Lectures on Electricity," this instrument will be familiar; but as this volume is likely to fall into the hands of many who have not seen the other work, a description of its use in this place may be useful, and even convenient to all. For the theory of the condenser, I must refer the reader to the volume on "Electricity."

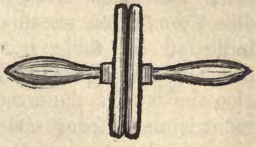
the uninsulated plate, S, is brought into close contact with the insulated plate, P, and afterwards withdrawn

Fig. 16.



a little, so as just to discern an opening between them. The plates of the condenser are now parallel to each other, with an exceedingly thin plate of air between them. The copper and zinc discs are then taken by their glass handles, one in each hand, and brought into contact with each other, as represented by fig. 17. They are afterwards suddenly separated, and one of them made to touch the cap of the electroscope. This operation is to be repeated six or eight times with the same disc—suppose the zinc, for instance. On withdrawing the plate, S, of the condenser from the other, the gold leaves diverge with *electro-positive* action. When the experiment is repeated, and the copper disc is made to touch the cap of the electroscope, the gold leaves diverge as before, when the uninsulated plate of the condensor is withdrawn, but they now show an *electro-negation*. When the single gold-leaf electroscope is employed, no condenser is necessary,

Fig. 17.

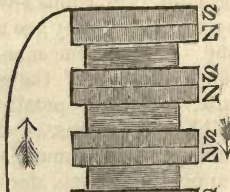


as a single contact of the discs is sufficient to detect an electrical development.

Notwithstanding the previous experiments of Sultzer, Creve, and Fabroni, already described, as well as those of Dr. Robinson, by which he detected an increased action on the tongue, when a series of pairs of copper and zinc plates were employed instead of a single pair, as in the original experiment of Sultzer, there is every reason to suppose that the success of Volta's experiment with the copper and zinc discs gave rise to his invention of the pile, already alluded to, and which must now be formally introduced as an implement of the highest importance in this branch of electricity, whether employed for the mere purpose of illustration, or in its still higher capacity when applied to physical research.

The pile, as originally constructed by Volta, consists of a number of pairs of silver and zinc discs, piled one upon another, with intervening discs of card-board, well soaked in water, in the manner represented by fig. 18. The silver discs first employed were pieces of coin, and the zinc pieces were cut to the same size; the surfaces of both metals, being made bright to insure contact, are placed together directly over one another, as indicated by their initials, z s, in the figure; which also shows that the arrangement is an uniform series of zinc, silver, moistened card-board—zinc, silver, moistened card-board, &c., from the bottom to the top of the pile, which terminates in a pair of the metals. The discs of card-board are smaller than the metals, to prevent the moisture from running over the edges of the plates, which would spoil the action.

Fig. 18.



With a pile of about fifty groups of these triplets

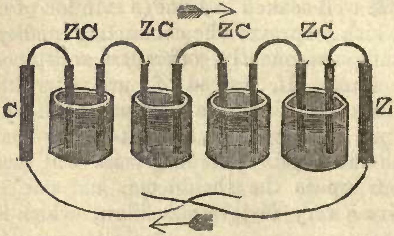
thus piled in series, a slight electric shock is produced, as high as the wrists, when the hands are made to communicate with the bottom and top of the pile. The effect is more powerful when the hands are well soaked in brine (a solution of common salt), which improves the conducting quality of the skin, and, consequently, offers less resistance to the electric force. If, instead of pure water, the card-board discs be soaked in a solution of salt, the power of the pile in delivering shocks to the animal frame is much increased. The fifty pairs will then shake the arms up to the shoulders; and one hundred pairs give a very disagreeable blow, which is felt in the chest.

The shocks from the pile are only produced at the moment of contact being made with the hands; and no repetition of that effect is perceived so long as the hands remain attached to the extremities of the instrument. But, although no shock is distinguishable, a burning sensation is experienced in the hands and wrists during the whole time of contact, and the roots of the finger-nails smart as if immersed in an acid solution. A wound in the skin, even the finest perforation with the point of a sharp needle, is rendered excessively painful by this electric action of the pile. This is occasioned by a current of the electric fluid running through the arms and chest of the person who is placed in the circuit, and also through the pile. Its direction is that indicated by the arrows, the pile being represented as if closed by a wire.

The pile of Volta was first made known in the year 1800, and in the same year this philosopher also invented his *couronne des tasses*, which is an elegant modification of the pile. The couronne des tasses consists of similar elements, or component parts, to those which constitute the pile, viz., a series of pairs of dissimilar metals, and a liquid. Fig. 19 will give a good idea of the structure of this apparatus. It consists of a series of small cups or

glasses, containing the liquid, which, usually, is either a solution of common salt or a weak solution

Fig. 19.



of some acid. The metals are copper, and zinc, in narrow strips, connected in pairs by an intervening copper wire, to the extremities of which they are soldered. The metals, thus connected, are immersed in the liquid, as represented in the figure, having the copper of each pair in one vessel, and its zinc in the next in the series, so that no individual pair of metals has both of its members in the same portion of liquid. The spare unimmersed copper, c, at one extremity of the apparatus, and the spare zinc, z, at the other, are shown in the figure to give a better idea of the arrangement; and the conducting wires attached to them are supposed to be in close contact where they cross one another, by which means the circuit becomes closed, and an electric current flows through the whole arrangement in the direction indicated by the arrows.

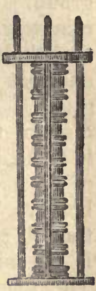
The invention of the pile and the couronne des tasses, may be regarded as the happiest events in the progress of Galvanism. Their announcement instilled a new zeal for experimental inquiries; their employment soon led to discoveries of the highest importance; and, in short, the invention of these apparatus commenced a new era in the history of the science.

Notwithstanding the several interesting discoveries that were made by the employment of these pieces

of apparatus in their original forms, experience soon taught philosophers that they might be modified with advantage in various processes of research. The pile, whatever may be the size of the metals employed, requires a tedious process to construct, especially when the metals are numerous, and not attached in pairs by solder; a mode of union not likely to be resorted to whilst half-crown pieces, or guineas, were employed as one of the metals, a practice very common in this country by the earliest experimenters with the pile. For as metallic contact in each individual pair is absolutely necessary, a considerable portion of time was occupied in cleaning the metals before the piling process commenced, a process no less tedious than the former.

Another inconvenience of the pile, when an extensive series of metals are employed, is its liability to tumble down. Accidents of this kind, however, are prevented by means of three glass rods, placed at equal distances from one another round the edges of the pile as supports. The glass rods should be well covered with either lac or sealing wax varnish, and their lower extremities firmly cemented into holes made for their reception on the upper side of a round wooden sole, as represented by fig. 20. The upper part of the pile, when thus supported, terminates in a metal disc, something larger than the discs forming the pile, for the double purpose of adding pressure to the upper pairs, and keeping the glass rods, which pass through it, steady in their proper places.

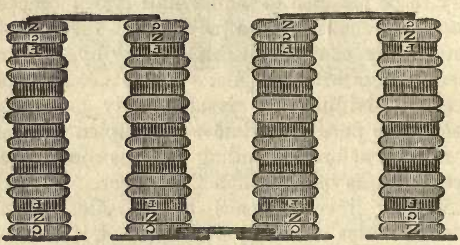
Fig. 20.



When the pile is tall, another inconvenience presents itself, over which the glass rods have no control. This is the oozing out of the liquid from the lower discs of card-board, by the pressure of the superincumbent portions of the pile. The liquid thus liberated, trickles over the edges of the metals, and destroys the insulation of

the pairs from one another. In order to avoid this annoyance, the series of pairs have been formed into several distinct groups or piles of moderate height, and so connected together as to act as one individual pile. Fig. 21 is a representation of an arrangement

Fig. 21.



of this kind, in which four small piles are united so as to operate in concert. The figure represents four groups united together by three metallic plates, by means of which the whole form one continued series from the bottom of the first to the bottom of the last group. To explain this apparatus a little more minutely, we must consider, in the first place, that the whole are piled on a well varnished glass plate, and that we commence at the bottom of the left-hand group. A metallic plate, somewhat larger than the discs of the pile, is first laid down. Upon this plate is laid a disc of copper, and upon the copper a disc of zinc, and upon the zinc a disc of moistened card-board. These three form one compound element of the pile; and a series of these, laid upon one another in the same order, form the first group or small pile. The second group from the left is formed in the reverse order to the first, having the copper of each pair *above* and the zinc *below*. The third group has its metals in the same order as in the first; and the fourth group is similar to the second, so that the arrangement in the first and third are alike, and that

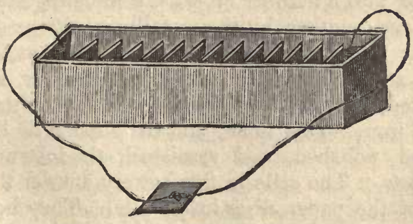
of the second and fourth are alike, but reverse with respect to the other two.

By connecting the first and second group with a metallic plate laid upon their uppermost metals, the two become one series, having its copper end at the bottom of the first group, and its zinc end at the bottom of the second one. In precisely the same manner the third and fourth groups are united, and form another distinct series; and by uniting the second and third groups at the bottom, the whole of the four groups become one uniformly continued series of *compound elements*, from the bottom of the first to the bottom of the fourth group.

By a similar distribution of the elements, a series of any required extent might be formed so as to operate in concert, without spoiling their insulation by squeezing out the water by superincumbent pressure; and when the metals are soldered together in pairs. which is now the usual practice, no cleaning for contact is required. Gold and silver coins have long been discontinued in the structure of Voltaic piles; copper and zinc are now the usual metals employed, and they are as frequently in square plates as in round ones.

The first modification which the pile received was by an ingenious contrivance of Dr. Cruickshank, of the Royal Military Hospital, at Woolwich, in the year 1800, a few months after the pile became known

Fig. 22.



in this country. Fig. 22 will afford a good idea of the Cruickshank's *trough*, or *battery*, as it is usually

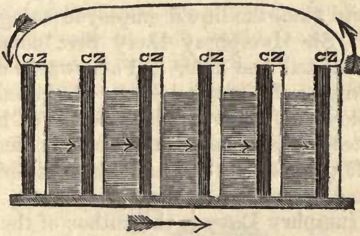
called. The metals are square flat pieces of copper and zinc, soldered together in pairs all round the edges, by soft solder, by which means a metallic contact between the copper and zinc of each pair is continually maintained without further trouble. When the soldering process is completed, the metals are filed smooth round their edges, and care is taken to have no openings in the soldered parts, and that the metals be all of one and the same size. The next business is to fix them in grooves made for their reception in the inner sides of a mahogany box, into which they should slip with ease till they reach the bottom. When thus placed, their planes stand parallel to the ends of the box, and, consequently, at right angles to its sides. When the plates are found to match their grooves, they are to be removed, and the box is to be lined with a resinous cement, composed of rosin, linseed oil, and red ochre. When the whole of the inside of the box is well lined with this cement, and the surplus cleared away from its edges, the plates are to be warmed (taking care not to melt the solder), and slipped into their respective grooves, observing that the zinc side of every pair faces one and the same end of the box. If the plates be ready warmed before the cement cools too far, they glide into their grooves very easily by employing a gentle pressure to their upper edges. A pair of pliers, or small pincers, is very convenient in this process.

When the plates are all introduced, they divide the box into a number of cells, completely separated from one another by the metallic partitions and the cement round their edges. The redundant cement, which stands above the edges of the plates, is to be removed, and the rest leveled and smoothed by a warm iron. This done, and the outside of the box cleaned, polished, and varnished, the instrument is complete. The cells in this battery answer the purpose of the paper discs in the pile. They hold the liquid, whatever kind may be chosen, when the battery is to be brought into play. A battery of

this kind, usually consists of fifty pairs of metals, which can be made ready for experiment in the course of a few minutes. It is well to have the edges of the trough a little higher than the plates, as it gives an opportunity of equalizing the height of the liquid in the whole of the cells, by leaning the battery a little on one side. Fig 22 represents an oblique view of a Cruickshank's battery when complete, having its conducting wires applied to some substance on which the battery is supposed to be acting.

Fig. 23 would represent a longitudinal section of

Fig. 23.



this battery, under the supposition of one of the sides of the box being removed. The edges of the pairs of copper and zinc plates are presented to view, and the cells are represented as when charged with the liquid to a proper height, each portion being insulated from every other. The zinc and copper ends of the battery are joined by a conducting wire, and the arrows show the direction of the electric current, as will be further explained when we come to speak of the theoretical principles upon which this and other pieces of Galvanic apparatus operate.

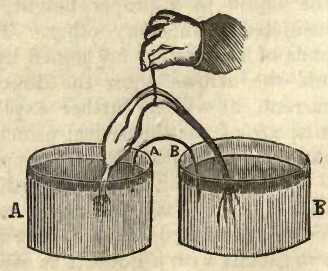
The Galvanic apparatus hitherto described, consists of two dissimilar metals and one liquid; and Volta entertained the idea, that such an association of two metals with a liquid was essential to the production of the phenomena which the pile exhibited, which

is the more remarkable, since he was well acquainted with several Galvanic arrangements in which one metal only was employed. M. M. Creve and Fabroni had shown that one of the metals might be substituted by charcoal; Galvani had shown that two metals were not absolutely essential for the production of convulsive motions in frogs; and Aldini and Valli had produced these phenomena independently of any metal being concerned in the process. Hence, data were not wanting to show the incorrectness of Volta's opinion on this topic.

If, instead of employing two metals, a pile be formed of slices of charcoal and plates of zinc, it is found more powerful than when the pairs consist of copper and zinc, the liquid employed being the same in both. Sir Humphrey Davy first constructed a pile of charcoal and zinc, and afterwards discovered that even one of these might be dispensed with by the employment of two distinct kinds of liquid; so that, instead of associating two solid bodies and one fluid, this philosopher formed a Galvanic pile of two liquids and one solid.

Sir Humphry Davy is the author of the following experiment, which shows the efficiency of a Galvanic association of two liquids and one solid in a beautiful and striking manner, and by means of an exceedingly simple apparatus. Fig. 24 represents two small glass vessels, one of which is nearly filled with a dilute solution of nitric acid, and the other with a solution of sulphuret of potassa. The liquids in the two glasses are joined by a piece of bent zinc, copper, silver, &c., as shown in the figure. The Galvanoscope for detecting the

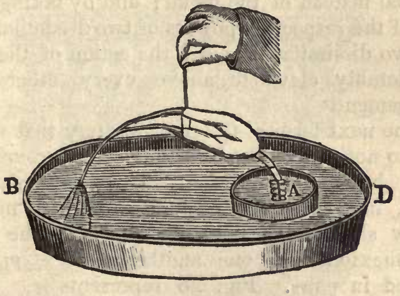
Fig. 24.



action of this arrangement, is a prepared frog, suspended from the hand by a thread of silk. When the legs of the animal are placed in one of the liquids, and the spine afterwards brought into contact with the other, the limbs are immediately thrown into the most violent convulsive agitation. The experiment may be varied by first immersing the spine and crural nerves, and afterwards bringing the toes to touch the surface of the other liquid. Charcoal may be employed instead of a metal, and the action on the animal is still as certain and complete. As the charcoal cannot be bent so as to reach into both liquids, it must be cut into a proper form, so as to accomplish that object when laid on the edges of the two glasses; or two straight pieces may be used, by immersing one in each liquid, and tying their upper ends together with thread.

This experiment may be varied by placing one of the liquids in a silver, or other metallic cup, and the cup on a dish containing the other liquid, as represented by fig. 25, in which, B D represents the

Fig. 25.

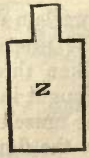


porcelain dish, and A the silver, or other metallic cup. The prepared limbs of a frog are suspended by a silken thread as before, and the crural nerves are brought into connexion with one of the liquids, and the muscles of the feet with the other, as represented by the figure.

After ascertaining that a considerable action can be obtained by a single Galvanic arrangement of one metal and two liquids, Davy was induced to form a pile of similar elements; and in order to keep the two liquids from mixing with each other, he placed between them discs of card-board steeped in distilled water. Davy's pile is thus constructed :—Provide a number of discs of sheet copper, or a number of half-crowns, also three times that number of discs of card-board, of less diameter than the metal. One-third of the card-board discs are to be soaked in a dilute solution of nitric acid, one-third in a solution of sulphuret of potassa, and the other third in pure water. Thus prepared, a disc of metal is to be placed on a glass plate, and upon the metal a disc of card-board, saturated with the solution of nitric acid; upon this a water-saturated disc, and upon the water a disc saturated with solution of the sulphuret of potassa. These form one compound element of the pile, which is completed by placing any required number of similar elements, in the same order, upon the first one. A similar pile may be formed by employing slices of charcoal instead of the metal; and by taking advantage of the respective powers of two dissimilar metals and two dissimilar liquids, the action of the pile is considerably elevated above every other known arrangement.

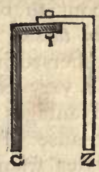
The next form of Galvanic battery that we shall have to notice, is a modification of the *couronne des tasses*, by Dr. Wilkinson. The copper and zinc plates, in this battery, are provided with necks, or narrow slips, at their upper edges, for the purpose of connexion with one another when coupled in pairs. Fig. 26 represents the shape of one of the flat sides of the zinc plates; but as the neck has a projecting piece on the other side, at right angles to its vertical part, it cannot be so well represented by an elevation of the flat side as by an edge view,

Fig. 26.



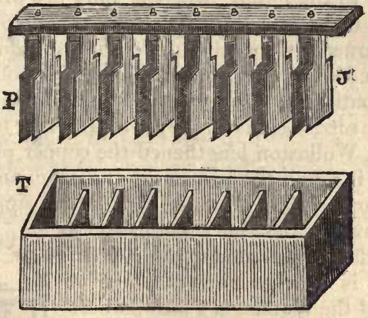
such as is shown in fig. 27, in which the unshaded part, z, represents the zinc, and the shaded part, c, the copper. The copper and zinc surfaces are of the same shape and magnitude, and fig. 27, which is an edge view of one pair, will afford a good idea of the method of keeping them in permanent contact with each other at the projecting parts of their necks, which is usually by means of a copper bolt and screw nut—one of the several errors that instrument-makers often fall into. The projecting pieces should be well *soldered* together, otherwise the contact becomes destroyed by the formation of an oxide of one, or both of the metals, where they lap over each other. I have seen very extensive batteries of this kind rendered entirely useless for want of attention to this particular.

Fig. 27.



When the metals are properly secured in pairs, they are fixed, by bolts and screw nuts, to a wooden beam; generally ten or twelve pairs to one beam, as represented by P J, fig 28. The planes of the plates

Fig. 28.

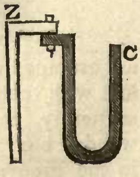


are arranged at right angles to the axis of the beam, and with their zincs all in one direction, and consequently, the copper plates all in the other. A wooden box, T, with glass partitions firmly cemented in the grooves in its sides, holds the liquid, into

which the plates are introduced when the battery is about to be used. In this case, as in the *couronne des tasses*, the copper and zinc of each pair are immersed in two vicinal portions of the liquid. This is a very convenient form of battery, and has some advantages over that invented by Cruickshank, because of the facility of speedily removing the plates from the liquid when any interruption occurs in a course of experiments, and of again introducing them when the experiments are about to be renewed. Shortly after the introduction of this battery as an implement of research, the wooden box, with its glass partitions, was happily superseded by a porcelain trough, with partitions of the same material. The Wedgewood ware, which withstands the action of acids, is most suitable for this purpose, and is that now generally made use of.

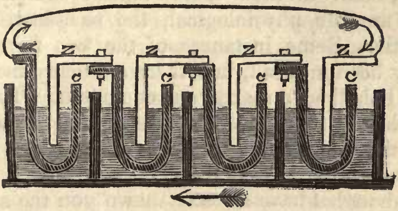
Dr. Wollaston, who took an active part in Galvanic enquiries, introduced a method of improving the action of Dr. Wilkinson's form of battery, by very simple means. It will have been noticed that the battery last described has all the metallic surfaces exposed to the liquid, whereas only *two* of the *four* surfaces in each cell *face each other*, the other two being turned in opposite directions, and do not add much to the power of the battery, although they suffer continually from the acid solution, especially when the nitric acid is employed. In order to remedy this evil, Wollaston lengthened the copper plate so as to bring it round the bottom of the zinc, and return up the other side of it as high as its upper edge. By this means the zinc plate has both of its surfaces presented to the copper. Fig. 29 is an edge view of a pair of metals of the Wollaston's form, where the unshaded part, z, represents the zinc, and the bent shaded part, c, represents the copper. They are united at the top in the same manner as the metals in Wilkinson's battery,

Fig. 29.



and also similarly fixed to a wooden beam in groups of ten or twelve pairs. Fig. 30 represents an edge view of a *series* of Wollaston's Galvanic pairs when immersed in the liquid in a partitioned Wedgewood ware trough. The figure also represents the connexion of the extremities of the series, by means of a conducting wire, and the arrows indicate the direction of the electric current.

Fig. 30.



The Galvanic apparatus hitherto described, are those alone, by which the grandest discoveries were made in this branch of science; and, although other modes of forming batteries have been brought forward of late years, some of which enhance the action, and others prolong it; and in certain illustrations and enquiries have an advantage over the older forms, it will not be necessary to describe their structures and uses until a later period of our course; nor, indeed, would it be advisable to dwell on them in this place, since some of those already described are more suitable than they are, for illustrating the theory of Galvanism, as well as for performing many of the necessary experiments.

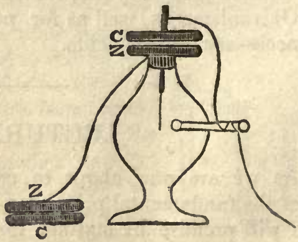
LECTURE V.

As we are now about to enter on an explanation of the fundamental principles of Galvanic Electricity, I will premise by stating, that electrical phenomena

are usually classified under two general heads, viz. Electro-statics, and Electro-dynamics. The former class comprehends every case of electric equilibrium; and the latter class comprehends every phenomena emanating from electric currents, whether momentary, or of long duration. Electro-dynamics being productive of a variety of effects of a widely different physical character, it becomes necessary for the convenience of illustration, to subdivide them into classes, and arrange them under distinct heads. These are the physiological, the chemical, and the magnetic. Some instances of the two former have already been noticed, but there are many more with which I shall soon make you acquainted. The magnetic class of phenomena will be but slightly touched on in this course, as a complete volume of lectures will be devoted to that subject.

Although I have already shewn you the action of a pair of copper and zinc plates, when separated from one another after close contact, I must here again introduce them, as the simplest and best of all known apparatus for illustrating the first principles of Galvanism. The plates employed in this elementary experiment need not be large, but they are better for being of a good substance or thickness. Those surfaces which are to be placed in contact with each other require to be quite flat and clean; but no such nicety is necessary on the other surfaces, nor are any glass handles wanted. The most delicate single gold-leaf electroscope is required, and also a condenser attached to it. Fig. 31 will show the apparatus by which the experiment may be successfully proceeded with.

Fig. 31.



The condenser of this apparatus consists of two discs of metal,

the one zinc and the other copper, placed horizontally one over the other, on the wooden cap of the electroscope; having three or four spots of sealing wax on the lower one, to keep them asunder with a thin plate of air between. There is a screw-hole in the centre of each plate, for the introduction of a stout wire. The figure represents the zinc plate screwed on the top of a brass wire which passes through the axis of the wooden cap of the electroscope; the lower end of the wire being attached by gum to the slip of gold leaf. The copper plate has a wire in its centre in the capacity of a handle, by which it can be removed from its present situation as we proceed in the experiment. It is connected with the moveable horizontal wire of the electroscope, and also with the ground by means of a thin copper wire.

The copper and zinc plates, which are the subjects of the experiment, are placed on the table, or, which is better, on the hand, with the zinc uppermost. If the hand be the support of the plates, it must not touch the upper one. One end of a thin wire is laid loosely on the zinc plate, and the other end rests against the zinc of the condenser. When the apparatus has remained thus arranged for a few seconds, remove the wire which joins the zinc plates, by a stick of glass, and afterwards the upper plate, by its wire handle. If the distance between the tip of the gold leaf and the vicinal ball be not too great, the former will immediately strike against the latter: shewing that an electric action has been communicated to the gold leaf.

If I wish to test the electric action thus communicated to the gold leaf, I place the ball at such a distance from it that it cannot strike, but only lean towards it. Then I bring a feebly excited stick of sealing wax (negatively electrical) gently over the cap of the electroscope, and I find that the gold leaf retires from the ball; showing that its tendancy to strike, and consequently, its electric action, in that

direction, is lessened: and that it is in an *electro-positive* state.

When the copper disc of the Voltaic pair is to be examined, the positions of the metals are to be reversed; and also the positions of the discs which form the condenser. The manipulation is precisely the same as in the other experiment, and the gold leaf indicates *electro-negation*. A more conclusive experiment than this cannot be made, to show the different electric conditions of the external surfaces of the Voltaic discs, when their inner surfaces are in intimate contact with each other; and from this fact we can easily understand, that any two metals similarly united, are, and must of necessity be, electro-polar. The polar condition is maintained when the two metals are soldered together; and even one, and the self same mass, of an individual metal, is electro-polar on its opposite surfaces, when not of the same degree of polish or texture. But these nice points of electricity we cannot pursue any farther in this place, as our present business is to explain the nature of Galvanic action in the simplest and clearest manner that the subject seems to admit of.

Having satisfied ourselves of the electro-polarity of a combined pair of metallic plates, we have little more than the functions of the condenser to bear in mind, to enable us to trace the combined electric actions of a series of pairs of metals, from one end to the other, however extensive the series might be. Let us suppose, for instance, that we first place a pair of copper and zinc plates upon a sheet of glass, or other insulator, with the zinc uppermost. In this pair we have a positive pole above, and a negative pole below. If now any plate of metal rested on three small dots of sealing wax over the zinc, these two would form a condenser, whose action would be increased by uninsulating the upper plate, and a greater facility afforded for accumulation of fluid on the zinc surface. If now, instead of a single disc of metal, we were to place upon the zinc another

Voltaic pair, with the copper downwards, this copper surface being already electro-negative by association with its own zinc, affords nearly, perhaps quite, the same facility for an electro-accumulation on the lower zinc, as the uninsulated plate of the condenser did. Moreover, the condenser formed between the zinc of the first pair and the copper of the second, would operate simultaneously and equally on both pairs, rendering them more highly polar than either of them could assume alone. And the polarity of either the top or bottom of this small pile, would be still further elevated by *uninsulating* the other end. For, by uninsulating one of the extreme plates, the functions of the two inner ones, in the capacity of a condenser, become increased; and, consequently, the facilities for polarizing the exterior *insulated* plate, become increased also. Therefore, by placing a finger on the uppermost zinc, the lowermost copper becomes more *electro-negative* than before; and for the same reason, touching the lowermost copper plate, gives rise to an elevation of the *electro-positive* action on the surface of the uppermost zinc.*

The electro-polarization of a single pair of metallic plates, and the mutual assistance which two pairs render each other in elevating their respective polar conditions, being clearly understood, there can be no difficulty presented in tracing the mutual assistance and combined actions of an extensive series, similarly arranged and piled upon one another. For since every additional pair brings with it an increment of polar force, and by its vicinity to the plate on which it stands, facilitates the polarization of all below, it acts in the double capacity of *contributor* and *condenser:* and thus not only adds to the former stock, its own increment of force, but facilitates the display of all the others.

* The whole doctrine of *electro-polarization*, with the operations of the CONDENSER, are clearly and minutely explained in my volume on Electricity, which ought to be well studied by those who wish to become proficients in Galvanism.

A series of pairs of metal, piled in the manner above described, form an apparatus called the *Dry Electric Column.* If we employ one hundred pairs only, and connect by a wire the upper end of the series with the cap of a single-leaf electroscope, an electric action is immediately indicated; and, by touching the bottom of the column with the finger, or destroying the insulation by any other means, the electroscopic action is much increased.

If the ball of the electroscope be placed too distant to be struck by the gold leaf, the latter will lean towards the former, whilst the bottom of the column remains uninsulated. And if, whilst thus in action, the connecting wire be removed by a dry glass rod, the gold leaf will retain its acquired electric state, which, on examination by the usual means, is found to be *electro-positive.* If now we neutralize the electroscope, and afterwards connect its cap with the *insulated* bottom of the column; the gold leaf again bends towards the ball when the finger is placed on the top of the column. Now strike the connecting wire away, with the glass rod, and test the electroscope, and it will be found to be *electro-negative.*

From the results thus afforded by the simplest of all *electric columns,* we become furnished with data of the highest importance, by enabling us to understand the first stages of electric action in every form of Galvanic, or Voltaic apparatus. In the *dry electric column,* the primative electric forces reside in the metals, which polarize each other by contact: and these increments of *disengaged* force, mutually assisting one another in polarizing the whole series, the zinc extremity becomes more highly charged as the series is more extensive: and, for the same reason, the *electro-negation* at the copper extremity is also increased.

With one hundred pairs of plates only, and thin strata of air between, the electrical indications are but slight. But when the series amounts to a thousand pairs, its action becomes palpable without much

nicety in the electroscopic manipulation. The principal difficulty that I have met with is in the formation of the pile, which must consist of several groups, as represented by fig. 21, and each stratum of air must be so thin, that the light can but just be discerned between the metals. The first *dry electric column* was made by Mr. Dyekhoff, about the year 1803.*

I have already shown in my lectures on electricity, that the polarization of bodies may be enhanced either by augmenting the disturbing force or by lessening the resistance of the intervening medium; and that the latter method is usually resorted to in the formation of dry electric columns, by the introduction of dry paper between the metallic pairs.

The invention of the *dry electric column*, as now formed, is frequently ascribed to De Luc: but M. Marechaux, was the first person who employed dry paper as the intervening medium,† which is the same as that employed in De Luc's columns. Marechaux called his apparatus, the *colonne pendule*. It was formed by piling forty-nine pairs of zinc and brass, with intervening pieces of card, "*not moistened*." The pile stood upon a brass plate, of greater dimensions, having three holes near its edges through which silken cords passed, by which the whole was suspended.

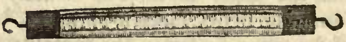
De Luc having discovered that the thinnest films of metal answer all the purposes of thick ones, formed the most of his piles of leaf silver and zinc foil. The silver is fixed by gum water to sheets of writing paper, and when dry is formed into round pieces, or discs by means of a punch. A small hole is made in the centre of every disc, for the purpose of being strung on a silken thread, in connexion with as many discs of zinc. A single ply of paper is too thin, and therefore three or four plys are strung between every pair of metals. When several hundreds of pairs are thus associated, and pressed close together, the whole

* See Annuals of Electricity, &c. Vol. viii. p. 378.

† Ibid.

are let down into a glass tube of a little greater diameter than that of the column. The tube being furnished with brass caps at its ends, the poles of the pile are in connexion with them, and these caps become the exterior polar terminations, whilst the body of the pile is within the tube which insulates it from the hand of the operator when in use. In the centre of the the end of each cap is a screw, which passes through to the inside, and presses upon the extreme metal for the purpose of keeping the whole as compact as possible. Fig. 32, is a representation of the apparatus when complete.

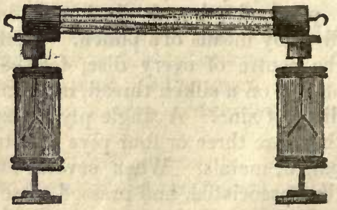
Fig. 32.



The tube usually contains a thousand pairs of metals. Its electric action is best shown by taking hold of one of the brass caps, and placing the other on the cap of a Bennet's gold leaf electroscope. The leaves immediately diverge to a considerable extent, and continue divergent after the pile has been removed, hence the electric state of either pole is easily determined by testing the electroscope in the usual way. The zinc end is always positive, with whatever metal it be associated, so that the silver end of this pile is electro-negative.

Although the action of either pole of an electric column is displayed to advantage when the other pole is, by some means, in connexion with the ground, the apparatus is as decided polar when the whole is perfectly insulated. To satisfy ourselves on this point, the instrument is placed on two electroscopes, having one pole on each, as represented by fig. 32. Both pairs of gold leaves diverge,

Fig. 33.



and to about the same extent. We now remove the pile by taking hold of the middle of the glass tube. The divergency continues, and by testing with excited sealing wax, or by glass, we find one of the electroscopes to be *electro-positive*, and the other *electro-negative*. We now again place the pile on the electroscopes as before; and when the leaves have become divergent, the pile is taken away, and laid aside. We now take hold of the foot of one of the electroscopes, and bring its cap into contact with the cap of the other. Both pairs of leaves immediately colapse, and fall close together: and, when care is taken in the experiment, both electroscopes, when again separated, remain perfectly neutral: showing that they were electrical to precisely the same degree, on opposite sides of the standard electric state of the air at that time. This is a beautiful and highly interesting experiment when well conducted.

When several columns are properly combined, by joining the positive pole of the first with the negative pole of the second, and the positive pole of the second with the negative pole of the third, and so on, in regular order of succession, the series may be continued to any required extent; and its poles will be at the extremities of the arrangement, and their respective *electro-positive* and *negative* states will be enhanced accordingly. Ten thousand pairs of metal will afford sparks, by bringing the points of a connecting wire to the cap of either pole, whilst its other extremity is united with the other pole of the series. Such a series, when in good action, will also charge *thin* coated glass: and twenty thousand pairs will charge Leyden jars of the usual thickness of glass.

The duration of the electric powers of a dry pile will depend upon the care that is taken to keep its metals free from every source of oxydation; for as the action depends upon the purity of those surfaces which are first placed in contact with each other, any change in them arising from oxydation, however slight, would tend to lessen the extent of metallic

contact, and by gradual encroachments, would eventually cover a whole surface with a film of oxide, and thus cut off the contact entirely. An occurrence of this kind in a single pair only, would not interfere greatly with the action of the remaining part of the column; but if the oxydizing process were to insinuate itself extensively into several parts of the series, the interruptions would not only materially impair its action, but might be the means of destroying it altogether. Therefore, notwithstanding the opinion that some philosophers entertain, that a *slow* oxydation of *one* of the metals is essential to the action of the pile, the only mode of perpetuating its powers, is to prevent chemical action taking place amongst its elements.

Every dry electric column that has been examined, subsequent to the total disappearance of its powers, has been found to have its metals tarnished in almost every pair; and those which have continued in action for the longest period, have been the best secured against attacks of this kind. Some there are which have continued their actions uninterruptedly for more than twenty years, and are still as active as at first; and there can be no cause shown why their powers should ever cease, whilst their constituent elements remain preserved without change.

Thin sheet copper, tinned on one side, makes an excellent dry pile, when interposed with three or four plys of white paper; and as the metallic contact cannot be interrupted without injury to the external surfaces, the only thing required to perpetuate its action is to secure it against moisture and other destructive agents.

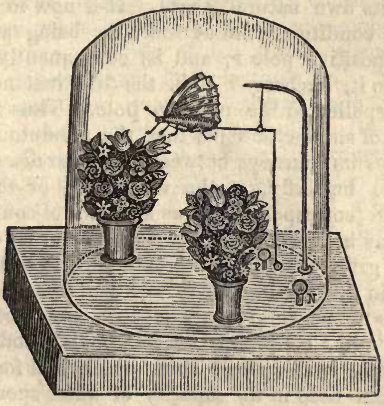
The electric columns invented by M. Zamboni consist of series of discs of tin foil, covered on one side with black oxide of manganese. These discs, when interposed by paper in the usual way, and strung on a silken thread which passes through their centres, are squeezed close together into a compact cylinder, and when thus under compression, the poles

are braced together by four silken cords. The whole column is afterwards immersed in melted sulphur, which, when cooled, forms an insulating case to the column. A series of one thousand elements displays an electric action on the double gold leaf electroscope; and ten thousand elements affords sparks perceivable in bright daylight. They will also charge coated glass when quite thin. A sheet of coated talc is charged by a moment's contact.

A series of Zamboni's piles, have long been employed as a source of motive power, to keep in motion light bodies, some of which are pendulous; others continue their motions in circular directions. The whole of these movements are accomplished by a series of alternate attractions and repulsions, and are amply illustrated in my seventh and twelfth lectures on Electricity; and by the theoretical examples there given, all others may be easily understood. I will, however, in this place, show you how one of the most fashionable of these pieces of apparatus operates.

The apparatus I am about to describe, has its *exterior* represented by fig. 36; but the interior,

Fig. 36.



which is the *virtual* operating part, is completely

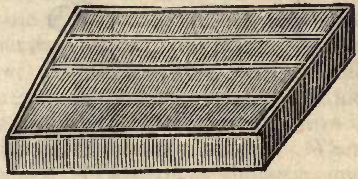
concealed. Within the box, which constitutes the base of the apparatus, are placed four of Zamboni's piles, laid horizontally, and properly connected with each other, to form one continued series. The poles of this series are insulated from each other, and terminate in two brass discs, P N, on the upper side of the box, being *positive* and *negative* respectively. Between these polar discs hangs a piece of thin platinum foil, which is attached to the lower end of a thin wire, bent at right angles, carrying a butterfly at the upper extremity, and suspended by a film of silk from the upper end of a stout brass wire, whose lower end is fixed in the upper side of the box, as shown by the figure. The angled wire, with its appendages, thus delicately suspended, are easily put into motion by any horizontal force acting on the disc of platinum which hangs between the polar discs, P, N, and the electrical forces of these poles are sufficient for this purpose.

In the first place, the platinum disc is drawn to the positive pole P, from which it receives a charge. It is then repelled to the negative disc N, to which it delivers up its redundant fluid, and also a portion of that of its own natural share. It is now in a more suitable condition than at first, for being attracted by the positive pole P, and is, consequently, again drawn to it, recharged as in the first instance, and again repelled to the negative pole. Thus it is, by a series of similar actions, that the pendulous body continues its journeys between the polar discs P, and N. The butterfly, at the upper end of the wire, moves in correspondence, as a matter of course, and a nosegay being placed just under each of its extreme ranges, gives an appearance of exquisite taste in the insect, in making its choice on which to settle.

It is now several years since I announced a dry electric pile, consisting of one metal and paper. The metal is thin sheet zinc, which had for a long time been used in the capacity of water spouting, at the Military College at Addiscombe. It was cut

into square pieces of about half an inch per side. One of the surfaces of each piece was made quite bright, with a fine file, and the other surface was left as I found it, covered with a thin coating of grey oxide. Six hundred of these were arranged in a wooden box, lined with window glass well varnished. The metals were placed edgewise with intervening paper, in four groups, with the bright surfaces of the first and third groups in one direction, and in the second and third groups in the opposite direction, so that a wire staple joining the first and second, and another staple joining the third and fourth, brought the whole into one continued series, whose positive and negative poles were at the *bright* and *dull* ends respectively. The groups were separated from one another by glass partitions as represented by fig. 34. The action of this arrangement, though not powerful, continues to be displayed, when applied to the electroscope, to the present time. A pile of ten similar elements will affect a delicate single leaf electroscope.

Fig. 34.

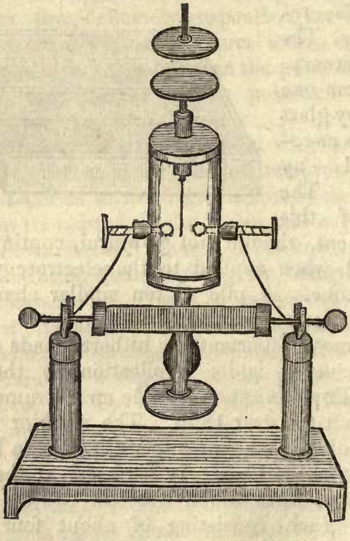


The most important use hitherto made of the *dry electric column*, is its application to the electroscope. Bonnenbergen made an instrument of this kind about the year 1820. The exterior of it is a cylinder of glass, about two inches and a half wide, and three inches high. It is closed at the top by a brass plate, from which descend two of De Luc's columns, each consisting of about four hundred pairs, of small dimensions, and terminated below by brass balls, one to a positive, the other to a negative pole. These columns are enclosed in glass tubes, and are placed an inch and a half distant from each other. Between the lower balls hang a pair of gold

leaves, from the lower end of a brass wire, enclosed in a glass tube, as in Singer's *insulator :* and to the top of the wire is screwed an horizontal brass plate. When any electric action is communicated to the gold leaves, they not only diverge, but one of them strikes that pole of the pile which is in the opposite electric state ; so that no subsequent testing is required.

In the year 1825, I made an electroscope for similar purposes, but of much greater delicacy, and of a more convenient form. Fig. 35 is a representation of the instrument in its first form. G is a glass

Fig. 35.



phial with its neck cut off, and perforated on its two opposite sides, for the introduction of two horizontal wires. These wires are formed into screws, and work in boxwood necks, which are firmly cemented to the bottle with their centres directly over the

perforations. Through the centre of a wooden cap, cemented to the top of the bottle, passes a brass wire, tapped at its upper extremity for the reception of a metallic plate, and from its lower extremity hangs a very narrow slip of gold leaf, pointed at its lower end, which reaches just as low as the inner balls of the horizontal wires. The bottle stands upon, and is cemented to, a neat boxwood pedestal, as shown in the figure. Upon two glass pillars, fixed to a wooden base, is placed, horizontally, a dry electric pile, consisting of about one hundred pairs, or rather, single pieces, of zinc, with bright and dull surfaces. The poles of this pile are connected with the two horizontal wires, by thin copper wires, as represented by the figure. By means of this instrument, the most delicate electric actions may be detected, when the side balls are screwed near to, and nicely adjusted on opposite sides of, the pendant gold leaf. In the figure, a zinc plate is represented as in connexion with the upper end of the axial wire; and above is shewn a copper plate with a wire handle. When these plates are about the size of a sixpence, and the copper pressed upon the zinc, the pendant leaf will lean towards the *negative* ball, and when the copper is suddenly lifted up, the leaf will strike. When the plates are reversed, the leaf leans towards, and strikes the *positive* ball.*

* This is the most sensitive electroscope I ever used, and by means of it I have been enabled to discover many electric actions which I could not detect by the employment of any other instrument. It was never before recorded, but was well known to Mr. James Marsh, of Woolwich, and other scientific gentlemen, shortly after it was first made. By means of this instrument, and the assistance of Mr. Marsh, we were enabled to ascertain the different electric states of the *inside* and *outside* of various articles of our clothing. Mr. Marsh's coat was always highly electrical, when pulled off after a smart walk, having its inside and outside in different states.

Since the original instrument got broken, at one of my Lectures at Addiscombe, I have had globular glasses, with necks at the sides, made for the purpose of forming the body of the instrument; which, with the exception of one of the side necks, is now of the shape of that represented by fig. 31.

LECTURE VI.

Although the dry electric column is in reality a permanently acting electric apparatus, its *rate* of action is by no means constant, but varies considerably according to the state of the surrounding air. In a warm dry room the activity of the instrument is much greater than when placed in a room in a less dry condition, which is partly owing to a better insulation, and partly due to the higher temperature; but the greatest activity is displayed when the air is highly charged with the electric fluid.

If we now turn our attention to the *wet pile* of Volta, or to the Cruickshank's battery (figs. 18, 21, and 22), charged with water only, we shall discover that these also are self-acting electric apparatus, and that they will produce divergency of the gold leaves of the electroscope—pendulous motions—emit sparks, and charge coated glass, in precisely the same manner as by any other means. Moreover, the electric states at the zinc and copper extremities, are positive and negative respectively, but of far superior tension to that of the dry pile, when both are of the same number of compound elements. One hundred pairs of the Cruickshank's battery will charge an extensive surface of coated glass, in a moment; but the *intensity* of the charge is very low. With this battery, however, as with the dry pile, the intensity increases with the extent of the series; and since piles can be connected in series, as represented by fig. 21, the intensity of a charge may be augmented to a considerable degree. There is, however, a limit of intensity beyond which we cannot pass, because the pile being placed in connexion with both surfaces of the glass, prevents the necessary insulation for charges of high intensity.

A series of Galvanic batteries, whatever may be their forms, are usually united so as to operate in concert, when high intensities are required. This

union of the batteries is accomplished by simply connecting the *copper end* of the first with the *zinc end* of the second, and the *copper end* of the second with the *zinc end* of the third; and so on, whatever may be the number of batteries employed in the series. The connexions are usually made by means of copper wire, suitably bent for immersion in the vicinal cells of every two consecutive batteries. Every series so arranged, forms a *compound Galvanic battery*. Batteries may also be combined *laterally*, so as to increase the metallic surface only, without extending the series. Suppose, for instance, that a battery of fifty pairs was of sufficient *intensity* for a certain purpose; but that, on the other hand, the size of the plates was too small to bring into play the requisite *quantity* of the electric fluid. Then, since the *quantity* depends upon the extent of metallic surface in action, it might be easily doubled by means of another similar battery placed by the side of the first, with their zinc ends united by copper wire, and their copper ends similarly connected. A third, and a fourth battery, might be added in a similar manner, and the *quantity* of fluid brought into play would be increased accordingly, without any increase of the *intensity* of action. It is thus that several batteries, consisting of *small* metallic plates, are much more serviceable than one individual battery with much larger plates, but considerably less in number. Where the means are not wanting, the best method of proceeding is to have a good supply of batteries of every size most likely to be wanted for each individual purpose.

In the employment of Galvanic batteries for the display of those phenomena which require purely electric tension, such is the attractions and repulsions in the charge of coated glass, &c., some precautions are necessary which need not be strictly attended to whilst employed for the production of other classes of phenomena. The principal things to be attended to for obtaining electrical tension, are the insulations,

which must be as perfect as possible, and the character of the liquid for charging the cells. Pure water has been found to answer better than any other liquid for the latter purpose; and two stout glass rods, well varnished, laid horizontally for each battery to rest on, insures good insulation.

The batteries which I employ for charging coated glass, consist of a hundred pairs of plates each, of the Cruickshank's form, each plate being one inch square. With ten of these batteries in series, charged with rain water, taking care not to fill the cells to the brim, a brilliant spark is produced, whenever the extreme poles are being connected by the usual *discharging rod*, represented by fig. 37, in which O G is a glass handle, attached to two bent brass wire arms which terminate with balls of the same metal, which can be brought closer together, or removed farther asunder, by means of a joint at O, to which they are fixed.

Fig. 37.

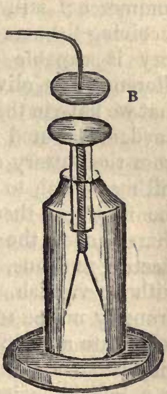
To make this experiment still more conspicuous than it can be done by the brass arms alone, I attach a piece of pointed iron wire to one of the arms, and a piece of copper wire to the other. The latter wire serves to unite that arm of the discharging rod with the negative pole of the Galvanic battery, and the iron wire, by suffering a trifling fusion, and scintillating at the time of the discharge, when brought to the positive pole, increases the brilliancy of the effect that would be produced by the mere spark alone.

To show that there is in this series of one thousand pairs, an electric tension sufficient to accomplish a continuous spontaneous discharge, I place a vertical wire, finely pointed at its upper extremity, in the positive pole of the battery, and on the point an exceedingly light electric fly, or rotating piece, such as that represented in fig. 33, page 90, in my lectures on Electricity; only, instead of having four discharging

points, this has but two. The cylinder forming the rotating piece is hollow, and made of thin writing paper, covered neatly with gold leaf. Through the centre of the cylinder, and at right angles to its axis, is a round hole, on one side of which is pasted a narrow slip of tin foil, which forms the cap or pivot hole; and at each extremity the point of a fine needle projects laterally. When this fly is delicately mounted and balanced on the supporting point, and covered with a glass shade, the finger placed on the negative pole of the battery gives an opportunity for a discharge of the electric fluid from the lateral points of the fly; and a slow rotatory motion soon commences, which gradually becomes more rapid, but never attains a great velocity.

Another method of showing the tension of this battery, is that by electro-polarization. For this purpose I employ a double gold-leafed electroscope, with a glass tube insulation, and a flat copper disc for its cap, as represented by fig. 38.

Fig. 38.



To one extremity of a stout bent wire, is attached a disc of brass in the manner shown in the figure, and the lower end of the wire is screwed into a metallic foot, made sufficiently heavy to overbalance the gravitating tendancy of the disc B. The apparatus is now placed on the positive pole of the battery, in such a manner that the disc B may project over the end of the trough, and sufficiently elevated for the electroscope to stand beneath it, without the two discs being close to each other. Being thus prepared, and the negative pole of the battery connected with the ground by copper wire, I bring the electroscope, gently, to beneath the projecting polar plate; and as the latter is approached by the plate

of the electroscope, the gold leaves diverge, but again collapse as the electroscope's plate is withdrawn. By gently moving the electroscope upwards and downwards beneath the polar plate of the battery, corresponding motions of the gold leaves may be continued for any required number of times. By this beautiful experiment, which may be varied many ways, we have ample illustration of the polarizing efficacy of the zinc end of the Galvanic battery; and by proceeding in a similar manner with the copper extremity, corresponding effects are produced.

To illustrate the electrical tension of the Galvanic battery still further, we next apply ourselves to experiments with coated glass, which, since the tension of the battery is very low, when compared to that of an electrical machine, ought to be as thin as it can possibly be made into the requisite form. The glass of Leyden jars is generally much thinner than that of those jars which are used for holding articles of commerce; still they are not sufficiently thin for receiving the maximum charge which a Galvanic battery is capable of communicating to glass. The Florence, or olive oil flasks, are the thinnest glass that we have in the shape of vessels; and these, when lined and coated with tin foil, receive a good charge from the battery of a thousand pairs. The metallic foil may reach to within half an inch of the mouth of the flask, as there is no fear of a spontaneous discharge over the edge of the glass with such low electric tensions, especially when it is well covered with lac varnish. When several of these flasks are properly united to form an *electrical battery*,* they constitute a very efficient piece of apparatus. They may be so numerous as to receive an immense charge, at a low intensity, which, for some enquiries, are more suitable than those of high intensity.

* Electrical batteries, and their uses, are fully described in my ninth lecture on Electricity.

Fig. 39.

To charge an ordinary Leyden jar, such as represented by fig. 39, we have only to unite the *lining* with the positive pole of the battery, by means of a copper wire, and the *coating* with the negative pole, by similar means; observing, however, that as the jar stands upon the table, there is no need of the connecting wire from the negative pole being insulated; indeed, it could not be insulated under such circumstances. The positive conducting wire must, however, be as completely insulated as circumstances will permit, and for convenience of preserving insulation of the inside of the jar, when removed from the battery, the wire joining the positive pole and the lining, should have one end fixed to the former, and its other end projecting so as to be easily brought into contact with, and separated from, the ring, or stem of the jar. During the charging process, the positive connecting wire is kept in contact with the ring of the jar, and afterwards removed from it. The jar now retains its acquired charge, and in order to ascertain its extent of electrization, its ring is brought into contact with the cap of a gold leaf electroscope, the leaves of which immediately diverge, and the angle formed by them gives an idea of the extent of electric action. It is by means of several experiments of this kind, made with different Galvanic batteries, still using the same jar and the same electroscope, that we are enabled to discover the different electric tensions of different numbers of pairs of metals; and as the divergency of the electroscopic leaves always increases by an increase of the Galvanic series, thence it is understood, that the electric tension also increases with every addition to the Galvanic series of elements employed.

This is not only the case with the *positive* pole

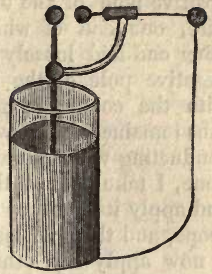
of the series, but also with the *negative* pole, whose effects on the electroscope, and powers of electrizing coated glass, follow the same rule. To electrize the inside of the jar *negatively*, we have only to reverse the former connexions; that is, the negative pole of the battery is brought into connexion with its lining, by touching a fixed copper wire attached to the former with the stem or ring of the latter, and connecting the outside coating with the positive pole of the battery. In a few seconds the electrization of the jar will be complete, and its inner surface is *electro-negative* to about the same extent as it was electro-positive by the former experiment.

Before we dismiss our extensive series of a thousand pairs of metals, it will be necessary to proceed with a few more experiments, in order to continue the analogy of the electric action of the Galvanic battery with that produced by the glass machine. If, for instance, we now charge the Leyden jar as before, and then remove it from the battery, we experience a shock by making the usual connexions with the hands. The shock from this single jar, however, is not great, but if we now employ a battery of jars, and charge them by the same means, we shall find that the shock is very powerful. Ten square feet of coated glass thus charged, would produce a severe and disagreeable shock, although the intensity of the charge would be very low. Five hundred feet of coated glass have been charged in less than one second of time, by a Galvanic battery of much less than one thousand pairs, but as the surface to be charged increases, the intensity of the charge becomes less.

Now, although much has been said respecting the promptitude with which glass is charged by a Galvanic battery, it may easily be shown by various experiments, that an appreciable time is required, after the connexions are made, to bring the charge up to its maximum. If, for instance, I employ a jar with the discharging electrometer of Lane, as

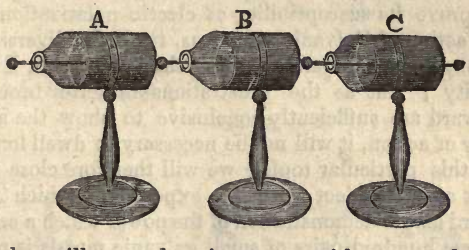
represented by fig. 40, and connect its inside with the positive pole of the battery, and the sliding wire with the outside of the jar, and also with the negative pole of the battery; then, by pushing up the moveable ball till it nearly touches the ball of the jar, a spontaneous discharge will take place between them in a short time afterwards, but not at the first moment. A series of sparks will, however, be seen between the two balls, but not a constant stream, which shows that *time* is required for the intensity to arrive at the discharging degree.

Fig. 40.



I will now endeavour to illustrate the analogy in question by another experiment, which, like the former, is rather a novelty in Galvanic Electricity. I employ the same three jars as were employed in an analagous experiment in my seventh lecture on Electricity. The jars A, B, C, fig. 41,* are supported

Fig. 41.



on glass pillars, and are in contact with one another in the following manner. The coating of A touches the ball of B, and the coating of B touches the ball of C.

* This experiment I make with thin Florence flasks, but for want of an engraving to represent them, I have been obliged to illustrate the arrangement by the present one.

Thus connected, I unite the lining of A with the positive pole of the battery, by means of a copper wire, one end of which is attached to it, and the other end laid loosely on the stem of the jar. The negative pole of the battery is similarly connected with the coating of the jar C. When things have thus remained for a few seconds, I remove the *positive* conducting wire by means of a dry glass rod. This done, I take hold of the glass support of the jar A, and apply its knob to the cap of a Bennet's electroscope, and the gold leaves diverge a small quantity. I now apply my other hand to the coating of the jar, and the divergency becomes immediately increased, for reasons shown in my twelfth lecture on Electricity. By testing the electroscope in the usual way, its electricity is found to be *positive*. By proceeding in the same manner with the jars B and C, their electric charges are found to be similar to the charge of A.

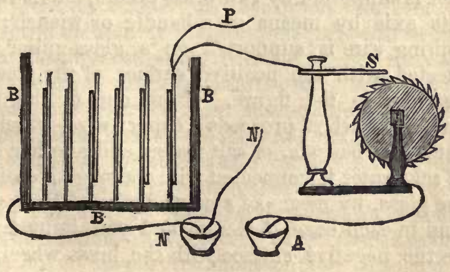
If the connexions of the extreme jars with the poles of the battery were to be reversed, then the inside of every jar would become electro-negative, and their outsides electro-positive. We might proceed with many more experiments with coated glass, to prove its susceptibility of electro-polarization by the action of Galvanic apparatus, in all the diversified arrangements of jars shown in the lectures on Electricity ; but as the illustrations hitherto brought forward are sufficiently conclusive to show the analogy of action, it will not be necessary to dwell longer on this particular topic ; we will therefore close this part of our subject with an experiment which will afford ample demonstration of the power which a series of one hundred pairs of small galvanic metals is possessed of, in the capacity of charging coated glass.

The Galvanic battery which I employ in this experiment, is of the Cruickshanks form, consisting of an hundred pairs of copper and zinc, each one inch square. The cells are charged with clean water. I also employ an elctrical battery of coated glass, con-

sisting of ten rectangular pieces of common thin window glass, each of which is twelve inches by eight and a half; hence, each surface is precisely 102 square inches, the double of which gives 204 square inches of surface for each piece. Therefore the ten pieces expose a surface of 2040 square inches of glass, and that part which is coated with tin foil, is about 1717 square inches; being little short of twelve square feet.

The coating of the glass consists of twenty rectangular pieces of tin foil, each about ten and a half inches by seven and three quarters. Each piece of tin foil, when fixed to one surface of glass, reaches to one of the longer edges, which it just covers, leaving a naked margin round the other three edges of that surface. The opposite surface is coated in the same manner, but the metallic foil now reaches the opposite edge of the glass, and also just covers that edge, leaving a naked margin of glass round the other three edges of the foil. In order to combine these coated panes of glass, so as to form an electrical battery, they are arranged in a grooved mahogany box, in precisely the same manner as are the plates of a Cruickshank's Galvanic battery, but not fixed in the grooves. The bottom part of the inside of the box is well covered with tin foil, on which the lower edges of the glass plates rest, and with the coatings of one side of which they keep good contact. B, B, B, fig. 42,

Fig. 42.



represents a vertical section of the box and six of the glass panes, as seen edgewise. On the *right hand*, the edge of each pane is delineated by a double line which reaches to the top, but not to the bottom ; and on the *left hand*, the double lines reach to the bottom, but not to the top. These *exterior* lines are intended to represent the metallic coatings, from which it will be understood that the whole of those on the left hand are in connexion with each other, by means of the metal lining at the bottom of the box ; and that those on the right hand, can at any time be united by a metallic rod being laid across the top of the series. This rod is not shown in the figure for the purpose of preventing confusion in the explanation.

The charging of these coated panes of glass is accomplished by connecting the lining of the box with the negative pole of the Galvanic battery, by means of copper wire N, and by means of another wire P, connecting the positive pole with the upper edges of the opposite coatings, or with the connecting rod that lays across them.

To illustrate the power of this apparatus in producing electric shocks, I use another piece of apparatus, by means of which a rapid succession of discharges can be produced ; and also a contrivance for throwing the whole of the force into a small compass on the person who is to receive the discharges. The apparatus for producing the discharges is an oblique toothed metallic wheel, and a spring wire. The former is supported by two brass pillars, and is turned on its axis by means of a handle or wiench ; and the spring wire is supported on a glass pillar, and connected with the positive surface of the glass, as represented in the figure. From one of the brass pillars of the wheel proceeds a copper wire, which terminates in a basin A, of salt water, and another basin N, of salt water is connected with the negative surface of the glass, by means of a copper wire. Now place a hand in each basin of water, and you immediately unite the negative surface with the brass wheel, but

prolong the circuit no farther, until, by turning the wheel, a tooth is brought into contact with the spring wire. By this contact, however, the circuit becomes closed, and the accompanying discharge produces a slight shock. I now keep turning the wheel at a moderate speed, and a succession of *openings* and *closings* of the circuit is thus effected, and the consequent discharges are attended by a corresponding series of shocks, which, though feeble individually, produce an extraordinary accumulation of effect.

If now you immerse one hand as much as possible in one portion of the salt water, and merely dip the little finger of the other hand into the water in the other basin, the former hand assists the conduction of the circuit, and consequently facilitates the flow of the electric fluid in every discharge, whilst the whole force is exerted on that portion of the little finger immersed in the water in the other basin. The sensation in the wholly immersed hand is now less than before, but that experienced in the little finger is too painful to be supported, even for a few seconds of time. By a similar distribution of the electric force a powerful sensation can easily be produced on any one part of the body, without any other part being much affected.

To convince you that the effect is due to discharges from the coated glass, we have only to remove that part of the apparatus, and arrange the wheel and spring with the Galvanic battery only, which produces scarcely any sensation whatever. A dry electric column of one hundred pairs will scarcely charge the thinnest glass, because of the resistance which the paper offers to polarization ; and as a thin plate of pure water is more susceptible of polarization than when suspended in, and mixed with, the fibres of paper, Cruickshank's battery has a greater power of charging glass than that possessed by the original Voltaic pile, when both consist of a similar series of metals. Moreover, since Cruickshank's battery has its metals the most suitably arranged for

mutually assisting each other in the polarizing process, its capabilities of charging coated glass are far superior to those displayed by any other form of Galvanic battery hitherto invented.

With respect to the size of the Galvanic metals for charging glass, it has generally been supposed that small ones answer quite as well as large ones, because of the idea of the *intensity* depending on the number only. This view of the action ought, however, to be taken conditionally, and not generally, and can only apply to a *limited* surface of coated glass. For a Galvanic series of one hundred pairs of one inch square, cannot charge to a *maximum intensity* any more than a certain extent of coated surface, although, to a *less intensity*, its powers might be distributed over a much larger area. But two such series would, separately, charge twice the extent of those surfaces to the same degrees of intensity respectively, and by multiplying the number of batteries the work performed would be proportionally augmented. Hence we learn that the *quantity* of coated surface which can be charged to a *maximum intensity*, by any given number of Galvanic plates in one battery, will be *directly* as the number of batteries are brought into play, the extent of series remaining the same. But multiplying the batteries without extending the series, amounts to nothing more than an extension of metallic surface; therefore it is, that a battery of one hundred pairs of one-inch plates would perform just one half the work that another battery would perform, whose plates were the same in number but double the surface; and a battery of the same number of plates, with three times the first surface, would perform three times the work, and so on. Therefore, the extent of coated glass that could be charged to a maximum intensity by any number of Galvanic pairs in series, is *directly proportional* to the size of the plates.

LECTURE VII.

WHILST carrying on our illustrations of the powers of the Galvanic battery in the capacity of charging coated glass, we have employed no other liquid in the cells than pure water, which, for that purpose, answers better than any other. But as we are now about to use it in a very different manner, and for the display of phenomena in which a *water-charge* would not produce the desired effect, we must employ such liquids as experience has shown to be most suitable for our present purpose. These are aqueous solutions of common salt, or weak solutions of some of the acids, accordingly as *battery power* is required. These solutions, however, are employed only for the display of physiological phenomena, and for the purposes of medical Galvanism.

When the battery is used for the production of chemical phenomena, its cells are sometimes charged with solutions of various salts, and in some cases with the most powerful acids.

It has already been shown, in our fourth lecture, that when the Voltaic pile is formed with discs of card-board steeped in brine, that it is capable of delivering considerable shocks to the person who places a hand on each pole, and as it was discovered that these effects were more powerful as the *series* of metallic pairs in the pile increased, they soon became augmented to such an extent, that the shocks produced by them were too powerful to be borne.

When a Galvanic pile or battery is excited by acid, or saline liquids, its effects on the animal economy are amongst the most remarkable of its phenomena; and as a stimulant to the vital powers, it has certainly no rival. Even after death the vital functions are recalled into a state of momentary activity by means of Galvanic agency, and in some few

cases resuscitation has been complete, and prolongation of life accomplished, by a judicious application of it. Aldini was amongst the first physiologists who operated on the larger animals with the Voltaic pile, and his experiments, which were prosecuted with great care, skill, and perseverance, were attended with the most promising results, viz., that the Galvanic apparatus would ultimately become triumphant over premature deaths, by its application in cases of suspended animation, and by renovating the vigour of bodily health where disease and affliction prevail over the ordinary modes of medical treatment, and baffle the contemplations of the most skilful physician. Although the lives of many animals were necessarily sacrificed for these experiments, they were wholly conducted in the cause of humanity, and Aldini was stimulated in his enquiries from the purest of motives.

"To conduct an energetic fluid to the general seat of all impressions; to distribute its influence to the different parts of the nervous and muscular systems; to continue, revive, and to command the vital powers; such," says Aldini, "are the objects of my researches, and such the advantages which I purpose to derive from the action of Galvanism. The discovery of the Galvanic pile by the celebrated Volta, has served as a guide to enable me to obtain the most interesting results, and to these I have been conducted by numerous researches, and a long series of experiments. I have examined the whole range of nature, and the grand family of animals has afforded me the means of making observations, highly interesting to physiology, on the whole economy of the vital powers."

Some of Aldini's earliest experiments were made on the head of a recently killed ox, and as they are of an interesting character, and easily performed, I will introduce a few of them in this place. The apparatus, whether it be a pile or a battery, and also the conducting wires, must be in readiness, in

order that there may be no delay when the head of the animal arrives. The head is to be placed on a table, as represented by fig. 43. We now introduce

Fig. 43.

one of the conducting wires to the spinal marrow exposed in the section, and occasionally touch the inside of the nostrils with the point of the other conductor. The nostrils will swell, and become agitated at every contact of the conducting wire, and sometimes the eyes are opened and the ears shaken at the same moment.

If now we moisten well the inside of both ears with salt and water, and then introduce one of the wires, permanently, in one ear, and bring the other wire, occasionally, into the other, the effects become more vigorously displayed than before. The whole head becomes convulsed. The eyes start wide open, the ears are thrown about, the lips quiver, and the muscles of the face are agitated and contracted, on every repetition of contact with the moveable conducting wire. A series of fifty pairs of plates, either in a pile, or a Cruickshank's battery, is sufficient to produce these convulsive motions; but with one hundred pairs of plates, the phenomena become displayed in a much more striking manner.

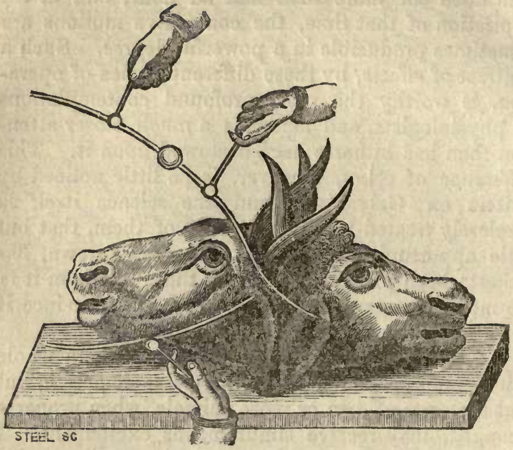
For the purpose of producing the best effects in this class of phenomena, the Cruickshank's battery has an advantage above all other forms, because of the facilities which it offers for communicating a rapid series of discharges through any part of the animal system, with a regular *increasing progression* of power. This series of successive discharges is accomplished by first fixing, in permanent contact, both conducting wires with the two parts of the animal, and one of them in one pole of the battery. This done, we take hold of the other wire, and, after making the first contact with the top of the battery, near to the same pole in which the other is fixed, we run it rapidly along the tops of the plates to the other pole. By these means, the continually increasing distance between the wires brings into play a corresponding increasing series of plates, and the magnitude of discharge through the animal increases also, by the wire's contact with every succeeding plate.

By proceeding in this manner, the face of the ox becomes hideously distorted, the ears flap about with great force, the mouth opens, the lips contract and expose the teeth, and the tongue is frequently protruded several inches. The whole head, in fact, is dreadfully convulsed. But by keeping the circuit closed, these motions are no longer seen, the head seems to resume a death-like tranquility, although a strong electric tide is pouring through it from the positive to the negative wire. When these connexions have remained a few seconds, we again remove one of the wires from the battery, and the head resumes its motions, but it is soon perceived that the vital powers have suffered a considerable degree of relaxation by the action of the continuous current, which for a few seconds traversed the head. A continuous current of one minute's duration, with a powerful battery, is sufficient, in most cases, to extinguish every spark of vitality; although, by

occasional discharges only, the vital powers will be continued for more than half an hour, and at the expiration of that time, the convulsive motions are sometimes producible in a powerful degree. Such a contrast of effects, by these different modes of operation, is worthy the most profound contemplations of physiologists, and demands a much closer attention than has hitherto been bestowed upon it. This difference of effect, however, is so little noticed by writers on Galvanism, and the science itself so carelessly treated by the generality of them, that but little opportunity of the fact becoming known, has hitherto been presented amongst those to whom it is the most important, and whose particular province it is, to make it an especial object of study.

It is very easy to show that not only a whole animal may be convulsed by the Galvanic action, but that the parts of two or more animals, when properly arranged, may receive simultaneous excitement. I will here present you with an experiment illustrative of this fact, which was first performed by Professor Aldini; and as it was the practice at that time, to employ glass handles to the discharging rods or conductors, it will be interesting to show the manner of manipulating with them. Most of Aldini's experiments were made with piles, and not with batteries, and the metals were usually silver and zinc, and the intervening card discs soaked in a strong solution of common salt. The heads of two recently killed oxen, being detached from the body, they are placed on a table with the sections of the necks in close contact with one another, as represented by fig. 44; and, as much of the success of the experiment depends upon an intimate connexion which the two heads have with each other, through the medium of the moisture at these sections, they cannot be too closely pressed together. As two operators are usually employed in experiments of this kind, one of them first forms a connexion, by means of his conducting wire, between the base of

Fig. 44.



the pile and one of the ears of the nearest head. The other operator, by means of a discharging rod, furnished with glass handles, now completes the circuit, by uniting the upper end of the pile with one of the ears of the other head, and at every successive contact both heads are affected, though by no means so powerfully as when one head only is operated on with the same Voltaic pile. In order to increase the conduction of the skin, the insides of the ears are well washed with a strong solution of salt, and the ends of the wires introduced to the cavity of the ears as far as the operator can get them conveniently.

A Cruickshank's battery of an hundred pairs of metals, of one inch square, produces a much better effect than a pile of the same extent of series, with the advantage also of communicating a rapid series of discharges, in the manner shown in the preceding experiment. The experiment may be varied on these two heads as decidedly as on any other subject, by making the connexions with the nostrils, mouth,

eyes, &c. For physiological experiments generally, the Cruickshank's battery is more convenient than any other form; the size of the plates need not in any case be more than four inches square, by which I mean each side is four inches long. In *Galvanic language* we denote the size of the plates by giving the length of one side only, it being considered that each plate exposes a square surface, because it is the common practice to make batteries of *square plates;* hence, when we are describing the size of a battery, we give the number in series of one-inch plates, two-inch plates, three-inch plates, &c. As for example: a battery of fifty pairs of four-inch plates, a battery of an hundred six-inch plates, and so on according to the *number* and *size* of the plates. There are, however, exceptions to this rule, because some batteries are formed of oblong plates, or such as are longer on one side than the other. Some of these we shall have to notice more particularly as we proceed.

In the frontispiece is given a representation of another arrangement of the heads of two oxen, subjected to the action of a Voltaic pile. This is also an experiment of Aldini's, and if it were on no other account than the peculiarity of the arrangement, it is well worthy of attention. It will be seen that both heads are operated on at the same time, and that they form portions of two distinct Galvanic circuits, one head being in each. This arrangement gives us an opportunity of understanding that the electric fluid brought into play by any Voltaic pile or battery, may be divided into several distinct currents, each of which may be sufficiently powerful for accomplishing some particular object. The fluid brought into play by the pile employed in this experiment, for example, affords two distinct currents, each of which is sufficiently powerful to produce strong convulsive motions in the head on which it operates; and every phenomenon exhibited by the animal is of the same character as if the whole force of the pile were exerted on it, although not in the same striking degree.

The commotions produced by a powerful battery on the head of a bullock, or an ox, are so vigorous, and the contractile forces of the muscles so strong, that no language can describe them. If the tongue be drawn out, as shown in one of the heads in the frontispiece, and held firmly in the hand, it is suddenly drawn into the mouth the first moment of closing the circuit, in spite of the efforts of the person who held it. The tongue, after being drawn out several inches, and fastened to the table by an iron skewer, has been known to be so forcibly contracted by a battery discharge, that it released itself from the skewer, threw it into the ceiling of the room, and drew itself into the mouth with one sudden and violent effort.

The effects of the same battery upon different kinds of animals are remarkably different from one another, and show that much of the action productive of the phenomena is due to the muscular powers of the animal itself. A battery which would produce the most violent commotions and muscular energy in the limbs and general system of a horse, an ox, or a deer, would develope but slight symptoms of its action on the body of a sheep, or a pig; and in general we find that the more muscular force which the animal naturally possesses, the more powerfully is that force displayed, when revived by Galvanic influence after death. For the mere purpose of illustrating the general features of the effects of a battery on a recently killed animal, we usually select a muscular rabbit, which is easily killed, and prepared for the experiment. When laid on the table in a dish, its fore and hind feet are placed together, as represented by fig. 45. A little below the head we pierce the spinal marrow with the point of a metallic skewer, the other

Fig. 45.

end of which is bent into a hook, or a ring; and a similar skewer is introduced to the muscles in the thick part of one of the thighs, as represented in the figure. From one end of a battery of fifty, two-inch plates, a wire is brought for connexion with one of the skewers. With this arrangement nothing particular is observed, but the moment the other skewer is touched by a wire proceeding from the other pole of the battery, the rabbit stretches forth the whole of its legs, and also its body, in a most surprising manner. The chest, moreover, rises and distends to an extreme degree, and a momentary hoarse squeaking noise is produced in the trachea by a sudden motion of the air between the mouth and the lungs. If, whilst the battery connexion is maintained with the skewer in the neck, the end of the other polar wire is brought to the angle of one of the eyes, that organ is immediately affected, and the eyelids open wide, whilst the eye-ball may be observed to be in motion and distended forward as that of a mad animal. More frequently, however, especially when the battery power is not great, the eyelids twinkle by a rapid series of quivering motions, whilst the eye itself is not much affected. By bringing the moveable conductor to the nostrils, a quivering is produced in the nose; and the lips exhibit similar phenomena when the wire is introduced to the angle of the mouth. I have operated on many cats, shortly after they were killed, and their struggles seem to be still more violent than those of any other animal that I have submitted to the action of the battery. On one occasion the connecting wire was introduced to the mouth of a fine large male cat, which, on closing the circuit, bit the wire nearly in two. After the animal had been submitted to a few volleys, by running one of the connecting wires over the tops of the battery plates, a portion of the wire which was in the cat's mouth was bitten into a thin film.

The first experiments that were made on the human subject, were by Creve, who operated upon an

amputated leg, which exhibited similar phenomena to those produced in the detached limbs of other animals. At Turin, many experiments were made upon the bodies of decapitated criminals, by Vassali Endi, Giulio, and Rossi. Other similar experiments were subsequently performed by Aldini, both in Italy, France, and in London. Those at the latter place, were made on the body of a criminal, who was hung at Newgate.

The phenomena exhibited by a Galvanized dead man, though not differing in character from those shown by other large animals, are much more calculated to exercise an influence over the minds of the spectators. And, although the physiologist's anxious researches stimulate him to make every effort to realize his hopes of resuscitating the subject of his experiment, and lead him calmly to a variety of modes of operating on the body, it is by no means surprising that the most horrid ideas should be awakened in the imaginations, and impressions of fear be produced in the minds of those who, for the first time, witness the extraordinary phenomena; amongst which we behold forcible and unnatural actions of the limbs, powerful and convulsive movements amongst the muscles of the face, with distended wildly rolling eyes; which, combined with the most ghastly grins and distortions of the mouth, present a spectacle of the most frightful description.

The results of a series of Galvanic experiments, performed on the body of Clydesdale, who was executed at Glasgow for murder, led the medical gentlemen present to infer, that, if certain precautions had been taken, resuscitation would have been accomplished, although the body had been suspended the usual period at the gallows, and much time afterwards occupied in preparatory arrangements for the Galvanic process. "An incision was made into the nape of the neck, close below the *occiput*. The posterior half of the *atlas vertebra* was then removed by bone forceps, when the spinal marrow was brought into

view. A profuse flow of liquid blood gushed from the wound, inundating the floor." These and several other unnecessary wounds were made in various parts of the subject, which rendered resuscitation impossible, with whatever judgment the Galvanic stimulus had been subsequently applied. But, notwithstanding the severe laceration of the spinal marrow, and almost total evacuation of blood from the body, even half an hour subsequently, a most interesting effect was produced. When one of the conducting wires was placed in an incision under the cartilage of the seventh rib, and the other applied to the phrenic nerve laid bare in the neck, having one of the conductors in permanent connexion with the battery, and the other run over the tops of the plates, in the manner already explained, "Full, nay, laborious breathing instantly commenced. The chest heaved, and fell; the belly was protruded, and again collapsed, with there laxing and retiring diaphragm;"* which was continued, uninterruptedly, during the whole time this Galvanic process was carried on.

The most successful Galvanic experiments on the human subject, were made on the body of John White, who was executed for murder, at Louisville, United States. The neck was not broken, and the body warm, and even trembling, having hung only about twenty-five minutes. "The poles of a powerful Galvanic pile, prepared for the occasion, were immediately applied to him. He suddenly arose from his bench to a sitting posture. He soon afterwards rose upon his feet, opened his eyes, and gave a terrific screech. His chest worked as if in respiration. One of the surgeons exclaimed, to the mute spectators, that he was alive. Whilst thus standing, another Galvanic discharge was administered, when White, with a sudden bound, disengaged himself from the wires and jumped to a corner of the room. Some short time afterwards he frequently opened his

* Ure's Chemical Dictionary.

eyes, and his breathing became so regular, that the doctors began to speak to him, but he heard not a word; nevertheless, by the assistance of a young medical student, who took hold of his arm, he arose, took a few steps on the floor, and seated himself in an arm-chair. He appeared overcome with the exertion thus made, but was revived by hartshorn applied to the nose. He looked like a man much intoxicated. He seemed to try to give utterance to some feelings, but he could not speak a word. Though now perfectly resuscitated, and every method resorted to for the purpose of equalizing the circulation, and save the patient, congestion on the brain, which increased with rapidity, shortly afterwards terminated his existence."†

The phenomena developed in these two cases, are of the highest importance in medical science; for, notwithstanding the want of success in resuscitating Clydesdale, and the eventual loss of White, there appear sufficient reasons for supposing, that both events were the natural consequences of the circumstances connected with the cases. In the former case resuscitation was impossible, for reasons already alluded to; and the fatal congestion which terminated the existence of White, was referrable to the violence of strangulation, and not easily traced to any other cause, excepting, however, the possibility of the Galvanic discharges being too powerful, and injudiciously directed. A powerful battery is never required for any medical purpose whatever, and may, by an injudicious application of its force, be the means of very serious consequences; whilst a battery of moderate power and properly employed, in similar cases, would be productive of the happiest effects. The battery employed on the body of Clydesdale, which consisted of 270 pairs of four-inch plates, brought into intense action by a solution of nitro-sulphuric acid, was far too powerful for purposes of

† Annals of Electricity, vol. vii.

this kind. I have already shown, that a few powerful discharges, or a continuous current of a few seconds' duration, hasten the extinction of vitality in those animals whose natural functions have been intentionally prostrated and laid dormant, for the purpose of experiment; and although a battery of fifty pairs, which would produce this effect on a rabbit, but not on a muscular man, that which was employed in the experiments on Clydesdale would be capable of subduing the vital energies, which remain after strangulation, even of an individual whose physical developments of organism were of the highest order in nature.

The tumefaction and lividity of the face, produced by strangulation at the gallows, enforce a strong probability that in no case of that kind would the functions of life be recalled into a natural state of activity, by the Galvanic influence. Resuscitation might be accomplished, as in the case of White, but for want of a natural distribution of the blood, and the injuries inflicted on its vessels, directly and indirectly by the rope, might prevent that promptitude and balance of circulation essential to the propagation of life, and all the evils consequent thereon would have to be apprehended.

The chances of success would be very different in those cases of asphyxia, occasioned by the inhaling of noxious gases, drowning, syncope, &c., in which no part of the system is deranged nor injured by violence; and the phenomena developed during the operations on Clydesdale and White, are promising indications of the most happy results being obtainable where the circumstances are of a more favourable description. A few moderate Galvanic discharges, well directed obliquely through the chest, from the neck on one side to below the ribs on the other, would diffuse their influence through the principal organs of life. By these means the respiratory organs might be expected to resume their natural functions, and the movements of the heart renew their natural impulses

to the blood, which, in these cases, would not have to encounter those difficulties of circulation, arising from congestion and injuries in the sanguiferous channels—the probable consequences of the rope. Running one of the connecting wires over the tops of the Galvanic plates would be the best mode of operating, for bringing the lungs into play, and a battery of one hundred three-inch plates would be sufficiently powerful to produce the necessary motions of the chest; and even that extent of Galvanic power should not be continued, if it was found that, by a less power, these motions could be maintained. As soon as the lungs would play independently of the Galvanic excitation, the battery action ought to be discontinued, and the usual restoratives gradually and cautiously administered.

The resuscitating powers of Galvanism have been confirmed in the most satisfactory manner, in some well conducted experiments by Mr. Halse, of Brent, near Ashburton. This gentleman drowned three young whelps in cold water, and three others, of the same litter, in warm water. The first three were immersed fifteen minutes, and the latter three forty-five minutes. The experiments were commenced immediately after the animals were removed from the water, and when all of them were quite motionless and apparently dead. Those which were drowned in the cold water, were placed on a blanket, in front of a good fire, and shortly afterwards one of them was prepared for the Galvanic process. Two small jars, containing a solution of common salt, being provided, the fore feet of the animal were placed in one of them, and the hind feet in the other, and a connecting wire from the battery brought to each jar, was immersed in the saline solution. The first *momentary* discharge developed signs of vitality; and a series of slight shocks continued for about five minutes, restored the functions of life. The poor creature was then again placed on the blanket, before the fire, and in a short time it began to walk

about, and appeared quite as lively as ever. On examining its two fellow-sufferers, they were found to be past recovery; indeed, quite dead. By operating in a similar manner on the other three, which were drowned in warm water, Mr. Halse succeeded in resuscitating two of them, and restoring them to perfect health; but the third dog, not being Galvanized till an hour after the resuscitation of the second, his efforts to restore it were not successful.*

It has been the opinion of many physiologists, that there is a strict analogy between Galvanism and the vital principle, and that the phenomena of life have an electric origin. Others there are who think they can indentify the nervous with the electric fluid. Be this as it may, the experiments of Dr. Wilson Philip, have shown, that there exists a striking analogy in the nervous and Galvanic *influences*, and that the latter is capable of supplying the place of the former, in performing the functions of life. Having fed several rabbits with parsley, Dr. Philip divided the eight pair of nerves of some of them, by incisions in the neck, for the purpose of ascertaining their influence on the digestive functions of the stomach. The breathing of these animals became more and more difficult, and, eventually, they died as if by suffocation. On examining the contents of their stomachs, the parsley appeared to have undergone no change whatever. Others of these rabbits were subjected to the Galvanic influence, by applying one of the conducting wires to the lower portion of the nerves, just below the incision in the neck, and the other conductor to the skin opposite to the stomach, so that the electric current would flow along the nerve. By this process the difficulty of breathing was prevented, during the whole of the twenty-six hours that the operation was continued. These rabbits were killed immediately after the Galvanism was discontinued, and the parsley was found to be

* Annals of Electricity, &c. vol. iv.

perfectly digested, and in the same state as that in the stomachs of other rabbits fed at the same time, and left unmolested in their natural healthy condition.

These capital electro-physiological results, which were subsequently confirmed by similar experiments, conducted by Dr. Clarke Able, leave no doubt respecting the influence of Galvanism, as a substitute in performing the nervous functions; and afford strong evidence of the practicability of applying this agency with advantage, as an *auxiliary* to the nervous energy, when the latter is too debilitated to act efficiently alone. The correctness of this view has been realized by the beneficial results that have been obtained by Galvanic treatment, in several cases arising from nervous debility, and the consequent atony of the organs which they influence. And as the muscles also become excited and invigorated by the Galvanic stimulus, the medical practitioner has, in it, a powerful auxiliary to his other modes of treating many of the diseases which afflict humanity.

The healing art has, already, been much enriched by judicious applications of Galvanism, much more so, indeed, than by the employment of the electrical machine; and as this stimulus appears to be capable of rousing the debilitated vital powers with greater promptitude and energy than any other known, there are yet ample opportunities afforded for the medical Galvanist to extend its sphere of usefulness much beyond that to which it has hitherto attained. The eighth pair of nerves, which have such an immense command over the functions of the respiratory and digestive organs, and biliary system, are necessarily important objects for pathological meditation, prior to the Galvanic influence being applied. It is probable that any defect in the performance of the functions of the two former, might, in many cases, be supplied by an electric current traversing the eighth pair from the neck, downwards to opposite the organ diseased, better than by any other route; but a diseased liver, arising from an accumulation of coagulated bile,

would be most likely to be relieved by transmitting the current directly through the organ, from one side of the body to the other. By this mode of attack, the obstinate consistency of the bile would soon yield to the influence of the current, and become reduced to a compartively thin liquid, susceptible of free motion in the ducts, and a final and easy discharge. Any obstruction to secretion which the liver might experience from the surcharge of bile, would thus be removed; and were tone wanting for the due performance of this function, assistance might probably be obtained from a feeble current, or from a series of feeble Galvanic discharges in the direction of the eighth pair from the neck, to the organ affected.

Dr. Wilson Philip has frequently employed Galvanism in cases of indigestion and biliary complaints. "I have employed Galvanism," says this eminent physiologist, "in many cases of habitual asthma, and almost uniformly with relief. The time during which the Galvanism was applied before the patient said that his breathing was easy, has varied from five minutes to a quarter of an hour. The cough under its use generally becomes less frequent in proportion as the accumulation of phlegm in the lungs is prevented. It is remarkable, that in several who had laboured under asthmatical breathing for ten or twenty years, it gave relief quite as readily as in more recent cases. In some labouring under the most chronic forms of phthisis, in whom the symptoms had lasted several years, the relief obtained from Galvanism was very great, notwithstanding the mixture of some pus-like substance in what was expectorated. The permanency of the good effects of Galvanism in the diseases before us has appeared very remarkable." When speaking of sanguineous apoplexy, Dr. Philip remarks, "after the rattling breathing had come on, and the patient seemed about to be suffocated, he was at least a dozen times made to breath with ease, the accumulation of phlegm

gradually disappearing on the application of Galvanism." The same philosopher observes, that in cases "where there was a failure in the secreting power of the liver, or a defective action of the gall tubes, I have repeatedly seen from it the same effect on the biliary system which arises from calomel: a copious bilious discharge from the bowels, coming on a few hours after the employment of Galvanism."

The beneficial effects of Galvanism in asthmatic and bilious complaints, have several times come under my own notice. Costiveness in the bowels, however obstinately it may resist the usual remedies, very soon yields to this mode of attack; and, by a similar process, constipations generally, may readily be vanquished. Rheumatic affections frequently yield more or less to the Galvanic influence, and in many cases of rheumatism, the patients have been completely cured in a very short time. Local pains in the limbs, arising from recent cold, are often removed by the first application of Galvanism; and although those of longer standing may require a few repetitions of the process, their violence becomes gradually diminished, and they eventually disappear.

Galvanism has also been successful in spasmodic affections, in rigidity of the muscles, in indolent tumours, or scrofulous swellings, in schirrous indurations of the breast, in gout, &c., in defective hearing, and in some affections of the eye. A singular result once occurred under my own observation whilst Galvanising a palsied arm of an elderly gentleman labouring under the effects of hemiphlegia. This limb was totally deprived both of motion and sensation, from the point of the shoulder to the ends of the fingers. In the first part of the Galvanic process the whole of the arm was brought into the Galvanic circuit, by connecting one pole of a battery, of an hundred pairs of plates, with the shoulder, and the other pole with the hand, which, for convenience of connexion, was immersed in a basin of salt water. By this mode of treatment

no good was done, nor did the patient experience any sensation whatever, although many volleys of discharges were transmitted. Whilst thinking on this *negative* result, it occurred to me that there might be a possibility of restoring sensation by operating only on a small portion of the limb at a time; and in order to ascertain how far this view might be correct, the line of demarcation between the sensitive and insensitive part of the limb was ascertained by pinching the skin about the shoulder and upper part of the arm. This being accomplished, one of the polar wires was brought into contact with the skin of the shoulder, on the sensitive side, and the other polar wire was brought to a little below it, on the insensitive side. The sensation was immediately restored as far as the lower wire, and, consequently, the line of demarcation was so far removed. By keeping the first wire permanently on the shoulder, and removing the other slowly downwards, making frequent enquiries of the patient if he experienced any sensation at the lower point, which was uniformly answered in the affirmative, we succeeded in restoring the sensation of the whole limb. This fact is one of those that is most deserving the attention of the physiologist and medical practitioner. It shows that the activity of a portion of a dormant nerve may be restored, without disturbing the slumber of the other portion of it; and also, that, although we might fail in restoring sensation to a limb by operating upon the whole of it at once, there might still be hopes of attaining the object by arousing the sensation *incrementally*, by an *electro-flunctional* process, such as that employed in the present case. There are, however, strong reasons to suppose, that success would not have attended the experiment, had the Galvanic process commenced at the hand, as there would have been a great portion of the dormant limb intervening between the sensative part on the shoulder, and the polar wire nearest to it. Nevertheless, it is an

experiment well worthy of trial, as it might probably lead to interesting physiological results.

The practice of medical Galvanism requires neither extensive nor costly apparatus. Two of Cruickshank's batteries, of fifty, three-inch plates, each, are sufficient for almost every purpose and one of these alone will answer for the generality of cases. But as the power of every Galvanic battery depends upon the character of the liquid with which it is charged, as well as on the number and size of its plates, the medical Galvanist should make himself well acquainted, as early as possible, with all the circumstances connected with the management of his batteries. Whilst a battery has its plates clean, and the surface of the zinc smooth, a solution of common salt answers very well for its charge; but when the zinc plates have become rough by long use, a weak solution of nitric acid will be necessary to bring the battery to the requisite state of activity, especially for rheumatic affections. But the only general rule that can be given, is simply this, never begin an operation with a high Galvanic power. The fluids of every part of the system are decomposable by Galvanic influence, and a powerful current traversing the head, or any part of the body, might be attended with serious consequences.

Galvanic operations on the head have, however, been frequently resorted to in cases of ear-ache, rheumatic affections, &c. &c. Fig. 46 will give an idea of the employment of a battery in a case of ear-ache. The two conducting wires are held in the hands of the operator, and one applied to each ear. In every case of this kind the battery ought to have a very weak charge of salt and water, for in all operations on the head, when the current traverses a considerable

Fig. 46.

part of it, a bright flash of light is seen by the patient, every time the circuit is closed, therefore it would not be advisable to deliver *volleys* through the head, by running one of the conducting wires over the edges of the plates, because such an operation would produce a rapid succession of flashes of lightning within the patient's head. It is very remarkable, that in Galvanic operations on the lower part of the head, the patient experiences a metallic taste in the mouth, which rises to an unpleasant degree when the conducting wires are placed just below the ears.

Although fig. 46 represents the application of a simple conducting wire to the affected parts, it is not to be understood that a mere wire is the proper apparatus for medical Galvanic operations. Its end, when applied to the skin, invariably gives pain, however smooth and well polished the metal may be; and, by condensing the Galvanic action to a mere point, is not unfrequently the cause of puncturing the skin, and a burning sensation is the consequence. If the wires are moved from place to place on the skin, wounds will be made at all the places of contact, which will be attended with a pungent smarting pain. These small wounds will sometimes remain for two or three weeks, and in some cases, for several months, after they were first inflicted. If the operator has no proper *electro-medical directors* at hand, and he is obliged to resort to simple wires, he should bend one end of each into a flat coil, about the size of a large button, and cover it with two or three folds of soft flannel. The flannel is to be well soaked in warm water, in which a little salt has been dissolved, prior to its application to the skin of the patient. This precaution protects the skin from injury, and by gently pressing the flat surface of the covered coil against it, the Galvanic force is spread over a larger surface.

The most elegant method of exhibiting medical Galvanism, is by means of the well known *directors*,

represented by fig. 47. Each director consists of a glass handle, and a stout brass wire stem, which terminates in a brass ball. The wire of one of the directors is usually bent into a curve, and the other straight; but, for Galvanic operations, they are more convenient when both wires are bent. The balls are screwed on the wires, and can be removed at pleasure; and replaced by flat metallic discs, which the Galvanist ought to be provided with. The wires screw into the centres of the discs, the flat surfaces of which, when covered with soft flannel, are to be applied to the parts operated on. To the stems of the directors, which must be clean, but not lacquered, the conducting wires are to be attached, either by means of a binding screw, or by twisting the conducting wire round the stems of the directors.

Fig. 47.

Fig. 48 will give an idea of a Galvanic operation on the muscles of the leg, in which the balls, covered with moist flannel, are used; but in all operations on the body, the discs are much preferable to the balls. In some cases, where irritation of the skin, or muscle, is required at one particular place, a naked ball may be applied, and a *flannel-guarded* disc maybe attached to the other director, which may be applied to any other part of the patient that the operater thinks proper. To excite the action of the bowels, the *guarded discs* are to be applied to opposite sides of the body; and moved about to different places, still keeping them opposite each other. A continuous current has generally a good effect in a short time; but in obstinate costiveness, the *volley* discharges are sometimes required. With female patients, Galvanic operations

Fig. 48.

on the abdomen should be conducted with the utmost caution, as excessive hæmorrhage is easily produced by them. The *guarded discs* need not be in contact with the skin, as the Galvanic action will pass through a thin linen or cotton robe, when moistened at the places of contact.—In many cases the patient can operate upon himself, without any assistance from any other person. This can be done on the lower limbs, the body, and even the head, provided he has courage enough to proceed. Fig. 49 will give an idea of one of the modes by which a patient can

Fig. 49.

Galvanize his face. One of the poles C, of the battery C Z, is connected by a wire K, with a solution of salt in a cup supported by a pedestal C, and the other pole Z, is connected with the face by a wire I D, having a ball M at its extremity. This wire passes through a glass tube, for the purpose of insulating it from the hand, and is connected with a piece of clock work, which alternately opens and closes the circuit with

great rapidity, by which means, an extensive number of discharges can be delivered in a short time. When the patient dips his fingers in the water in the cup, and holds the ball M to his cheek, a continuous current would traverse every part of his person between the two points of connexion; that is, it would traverse the hand, arm, chest, neck, and the right side of the face to the ball M, but by means of the clock work in the box I D, the current becomes interrupted and broken into a number of momentary discharges, which for nervous affections in the face will sometimes answer better.

Persons operating on themselves will find the directors, fig. 47, more convenient than any other piece of apparatus, and a foot-pan will occasionally be useful, especially for operations on the legs and thighs. If both limbs be affected, the feet may be immersed in two separate portions of warm water, and the connecting wires from the battery connected with them—one with each portion of water. If the battery connexions be not disturbed, an electric current will flow up one limb and down the other, and produce a thrilling warmness in both. If the case requires a series of shocks, the patient may easily deliver them to his limbs, by running one of the conducting wires over the edges of the battery plates. Many other means of operating will suggest themselves to a patient who is determined to Galvanize himself. Since the discovery of Magnetic Electricity, several fashions of what are called *coil machines* have been invented, which, in consequence of their being self-acting, are very convenient for persons operating on themselves. These will be minutely described in my lectures on Magnetic Electricity.

LECTURE VIII.

In my third lecture of the present course, I have brought forward those experiments of Creve and Fabroni, in which the decomposition of water and other chemical phenomena were displayed; and as we are now about to enter the interesting field of electro-chemistry somewhat extensively, for the purpose of exhibiting to you the treasures which it contains, and examining them minutely, it will be necessary that your attention be again directed to those beautiful experiments, in which the first germs of this division of our subject were developed; a division of Galvanism, which, in its present state of cultivation, assumes such an immense degree of importance in experimental philosophy, as justly to entitle it to the dignity of a distinct branch of science.

In the experiments of Creve and Fabroni, the metals that were employed had contact with each other *below* the surface of the water; but it is now well known that it is a matter of no consequence whether the metals, constituting a Galvanic pair, touch each other *below*, or *above*, the surface of the water; the result, as far as its character is concerned, will be precisely the same in both cases. If, for example, we take a slip of zinc, made perfectly bright, and also a slip of copper, and bend the latter in such a manner that it shall hang freely on the upper end of the former, without touching any other part of it; and place this Galvanic pair in a glass vessel, containing pure water, in the manner represented by fig. 50, the electro-chemical action will immediately commence, and in a short time a streak of black oxide will appear on the zinc surface, directly opposite to the vicinal edge of the copper, as far as both are immersed below the surface of the water, showing that the metallic contact on the outside of the water is as efficient, for

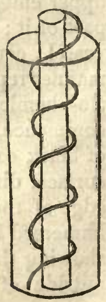
Fig. 50.

this species of Galvanic action, as when the contact is below the liquid surface. The copper side of this Galvanic pair may be a wire, which will be found more convenient than a strip of that metal.

This instructive experiment may be varied many ways, some of which I will now describe. If, instead of allowing that part of the copper wire which is below the surface of the water to hang parallel to the face of the zinc, we were to bend it in such a manner, that its *lower point* only, should be presented to the zinc, the principal electro-chemical action would be found to take place directly opposite to the copper point, as would be indicated by a small black dot appearing on the zinc surface, without any corresponding change on any other part of it.

If the lower end of the copper wire be bent into the shape of a round loop, and the flat side or plane of the loop be presented close to the bright surface of the zinc, but not in contact, a ring of black oxide, corresponding to the copper ring, will soon appear on the surface of the zinc. When the copper wire is bent into a flat spiral shape, and the flat side of the spiral is presented to the zinc, a curious picture of the spiral is soon formed on the zinc surface, by the oxide of that metal, formed as a result of the decomposition of water by this simple electro-chemical process.

Fig. 51.



Another interesting variation of the experiment is made by employing a cylinder of zinc, surrounded by an elongated spiral of copper wire, in the manner represented by fig. 51. When the two metals are in close contact with each other, either by solder or binding together, at their upper extremities only, they are to be immersed in a vessel of water, and permitted to remain unmolested for an hour or longer. On inspection, either whilst the metals are in the water, or after they are taken out, a black spiral band will be

seen on the surface of the zinc, corresponding to the spiral copper wire which formed one of the Galvanic metals.

From the examples thus given, it will be easily understood, that a great diversity of electro-chemical pictures may be formed by this simple process ; and, although these pictures do not display to the eye that degree of beauty which some others, soon to be noticed, are possessed of ; they are sister phenomena of the same family, and productions of the same agent ; and, in the philosopher's estimation, are of equal beauty and importance.

It has already been shown that a Galvanic action of considerable power, is produced by an association of one metal with two distinct kinds of liquid ; from which fact we learn, that the liquids employed in all Galvanic arrangements have a considerable degree of influence in the production of electric currents ; and that this influence may either assist, or operate against, the electric action of the metals. It is, indeed, a well established fact, that one and the same pair of metals will produce a current more or less energetic, according to the character of the liquid in which they are immersed. A Galvanic pair of copper and zinc, for example, produces a more energetic current by immersion in brine than in common water: and a still more energetic current when immersed in a solution of sulphuric, nitric, or muriatic acid, than when immersed in brine.

There are various modes of ascertaining the *relative powers* of Galvanic batteries, piles, or even single pairs of metal ; and there are also certain phenomena displayed by electric currents, which are available as data, whereby the *direction* of those currents can be ascertained. The *powers* of Galvanic batteries, &c. will always be comparable by the *quantity* of work done by them in a certain period of time. But I shall have to show you, as we proceed, that a battery, which we will call A, may be more powerful than another battery B, in the production of a certain class

of phenomena, though of far inferior power to B, in the production of another class of phenomena. Hence, the work which a battery will perform in one department of Galvanism, is no criterion for the work which it is capable of performing in another department. The most striking demonstration of this fact is displayed by comparing the circumstances under which glass is charged, and those which are productive of electro-chemical phenomena. The water charged battery charges glass to the best advantage, whilst the acid charged battery performs chemistry to the best advantage. Moreover, the power displayed in the former capacity, depends upon the extent of the Galvanic series, when the plates are of a given size; but the power in the latter capacity, depends upon a very different distribution of the metals, for beyond a certain extent of series, the chemical powers begin to lessen. Therefore it is, that no one *individual battery* will be productive of maximum effects in all the different departments of Galvanism. To produce phenomena of this or that kind, to the best advantage, we must employ a battery most suitable for that particular purpose; and to produce another class of phenomena advantageously, another, and a very different battery must be employed.

The phenomena which are indicative of the *direction* of an electric current by Galvanic apparatus are of two kinds, *chemical* and *magnetical*, and are known by their relations to similar phenomena produced by the electric machine, Leyden jar, &c. I have shown in my tenth lecture on electricity, that certain fluid compounds are decomposed by electric currents from the prime conductor of the machine; and that by virtue of an immutable law, a certain class of the elementary bodies which constituted those compounds, are invariably collected at a certain place in the circuit; and that another class of elements are collected at another place in the circuit, with reference to the direction of the current. If, for example, a platinum wire hanging from the prime conductor were to *deliver*

electric fluid to a pile of paper, well soaked in a solution of hydriodate of potassa, the current thus produced would accomplish the decomposition of the hydriodate, and the liberated iodine would appear on the upper surface of the paper, directly beneath the point of the *delivering* wire; but no iodine would be seen on the lower side of the paper, although the point of another platinum wire were pressed against it to *receive* the current from the liquid. Since then, these results are invariably the same under all circumstances, they may be considered to be the type of an immutable law in electro-decompositions, in which certain liberated elements uniformly assemble at the *delivering metal;* and, as will presently be seen, other certain elements are as uniformly assembled at the *receiving metal.*

Relying upon the immutability of this law, we proceed to a Galvanic operation on another portion of the same compound body. We take, for instance, a slip of copper and another of zinc, and to each we attach a piece of platinum wire, and immerse the Galvanic pair in brine, or in any weak acid solution; and having prepared a thin pile of white blotting paper, well soaked in a strong solution of hydriodate of potassa, we press the ends of the platinum wires against its two opposite sides. In two or three seconds of time we perceive a brown spot of liberated iodine all around the point of that wire which is attached to the copper-plate, but not any change of colour is discoverable on the other side of the paper pile. Now, from the fact that liberated iodine appears on one side of the paper pile only, and not any visible change taking place on the other surface, in both of these experimental processes, we cannot avoid the inference that the iodine appears at the *delivering* metal in one case as decidedly as in the other; therefore, taking the appearance of the iodine to be indicative of the *delivering metal* being on the same side of the pile of paper, we at once descern the *direction* of the current, which, in this case, is *from* the copper *to* the zinc through the pile of paper; and, consequently, *from*

the zinc *to* the copper, *through the liquid* in which these metals are immersed.

Another example is afforded by operating on a solution of sulphate of copper, either suspended in soft paper or placed on a piece of glass. If the ends of the two platinum wires which are attached to the voltaic pair, be immersed in a drop of a strong solution of sulphate of copper, that wire which belongs to the zinc will soon become coated with metallic copper, but the other wire will undergo no visible change. Now this is precisely the case when, from a prime conductor, a current is conveyed *to* and *from* a drop of the solution of sulphate of copper, by a similar application of the wires. But, by this machine process, the copper-coated wire is that which *receives* the current *from* the *cuperous solution;* therefore we infer, that in the Galvanic process also, the *receiving* wire is that which becomes coated with copper.

Another mode of ascertaining the *direction* of Galvanic currents is, by comparing their magnetic effects, with the magnetic effects of discharges from a Leyden jar, from which it is found that the indications are in strict accordance with those afforded by the chemical processes already shown in the two previous experiments. Having thus got possession of the information necessary for understanding the direction of the electric current, produced by a Galvanic pair of copper and zinc, we are enabled to ascertain the direction of any other electric current of sufficient power to produce these phenomena, from whatever source it may proceed.

To those who are uninitiated in Galvanic contemplations, there appear some considerable anomalies in the operations of a single pair of metals, and in those of a series, or a battery; and the *confusion of ideas* which the Wollaston battery (fig. 30, p. 67) has created, is an infliction, on some persons, not much less severe than that which befel the builders of Babel, by the confusion of tongues. The action and the mode of action are, however, of the same kind, when

the materials are of the same kind, whatever form the Galvanic arrangement may assume, whether it consist of a single pair or of a number of pairs, in series; or whether it be a pile, a couronne des tasses, or a battery of a simple or of a complicated form. And as it is essential that this fact should be well understood before we proceed with other illustrations, I will endeavour to simplify it in this place, premising by a few elementary experiments.

Fig. 52.

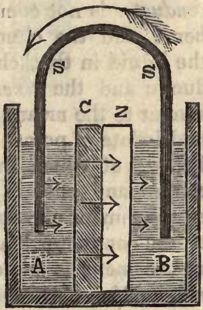


Fig. 52 is a representation of a perfectly watertight wooden box, separated into two compartments, by means of a voltaic pair of metals c z, which form a watertight partition. The copper and zinc plates c z are soldered together, and are represented as seen edgewise, and in each compartment is a portion of brine or of acidulated water. Whilst the two portions of liquid have no other connection with each other than through the medium of the Voltaic pair, an *electric equilibrium* prevails in every part of the compound mass, both metal and liquid.* But if we connect the two portions of liquid by means of a bent copper wire s s, or a strip of sheet copper, immediately an electric current commences, which flows through the connecting wire in the direction of the large arrow; and through the liquid and the voltaic pair c z, in the direction indicated by the small darts. If now instead of the copper wire connexion, we were to remove that wire, and connect the two portions of liquid by a similar liquid contained in an inverted glass syphon, which s s may also represent, an electric current would again be excited, and its course through the voltaic pair c z would still be in the same direction as before; and through the syphon as

* The chemical action on the zinc is here neglected, for the purpose of simplifying the explanations.

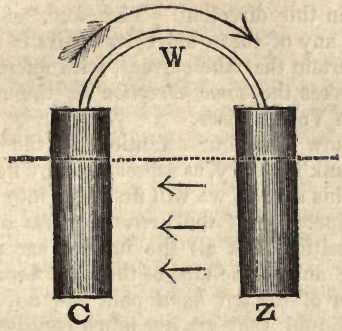
through the wire which it replaced, so that the arrow and darts indicate the route of the currents under both circumstances.

If, now, we consider a voltaic pair to be formed by the zinc of the *fixed* pair, and that portion of the copper conductor S S, which is immersed in the same portion of the liquid B, the other part of the copper conductor will carry the current to the liquid in the chamber A, which will conduct it forward to the *fixed* copper C. Under these circumstances the *metallic conductor* is not complete, being broken in the chamber A, and the circuit is completed by a portion of the liquid in that chamber between the copper conductor and the *fixed copper* C. The arrangement is similar to the arrangements in the experiments on the hydriodate of potash and the sulphate of copper, page 123, all of which show that an *actual contact* of the copper and zinc is not absolutely essential to the establishment of an electric current, and that a portion of the conductor may consist of liquid matter. This arrangement is one of the *elementary types* to which we shall have to refer as we proceed in the explanation of the action in the compound battery.

Another *type* of reference is afforded by the arrangement in which the glass syphon formed a part, and in which the *fixed voltaic pair* C Z, were obviously the operating metals.

In this arrangement the connexion of the two portions of liquid A B, by means of a similar liquid in the syphon, amounts to the same thing as if both metals were in one and the same portion of liquid, and a modification of it, as represented by fig. 53, will afford a *third type* of reference, in which the bent arrow indicates the direction of the current in the connecting wire W, to be *from* the copper *to* the zinc; and the three darts show its direction through the liquid from the zinc to the copper. In all these arrangements it will be observed, that the current flows in one uniform direction, in reference to the metals and liquids employed.

Fig. 53.



A fourth type to which we shall have to refer, would be represented by fig. 52, under the supposition of connecting arc s s, being partly copper and partly zinc, and that the zinc part were immersed in the liquid A, and the copper part in the liquid B. By this arrangement four pairs of plates would be brought into play, the fixed pair C Z; the pair s s; the pair formed by the zinc of the fixed pair, and the copper of the conductor in the cell B; and also the pair formed by the copper C of the fixed pair, and the zinc of the conductor s s, which is immersed in the liquid A.

We are now in possession of all the necessary data for entering on an explanation of the *uniformity* with which the copper and zinc operate in every shape of battery constructed of these metals. We have seen by the experiments with the Voltaic discs, (p. 53, 68,) that, when in contact, the copper communicates a portion of its natural charge to the zinc, and, consequently, that at the time of this transference of the electric fluid, there is a momentary current *from* the copper *to* the zinc. We have also seen by all the four elementary types, that the transference is still *from* the copper *to* the zinc, *through the metallic connexion*, when the plates are immersed in brine, or

in acidulous liquor; and also, that actual metallic contact is not absolutely essential for the current to proceed in this direction. Therefore, as far as the action of any of these individual pairs is concerned, we are certain that the current, with reference to the metals, takes the *same direction* as the momentary current in Volta's discs.

We now turn our attention to the section of Cruickshank's battery, as represented by fig. 23, page 61. In this section we will first take into consideration the operation of the *extreme plates* only, under the supposition that all the intervening pairs were removed; and as the zinc of the *right hand* pair, and the copper of the *left hand* pair, are not in contact with the liquid, they are not much concerned, otherwise than as conductors, in the Galvanic action, hence the metals which come under our consideration are the copper on the *right hand*, and the zinc on the *left;* and the arrows indicate the current *through the conducting wire*, to flow *from* the copper *to* the zinc, as in all other cases of a *single pair*, a type of which is fig. 53.

In order to assist our explanation of the manner in which the intervening pairs operate, it will be convenient to number them from one end of the battery, to the other. We will therefore commence with the right hand pair of plates, which will be number 1, and the left hand pair will be number 6. If now we introduce number 2, and consider that 3, 4, and 5, are still left out of the battery, we shall have two distinct portions of liquid, and in each a distinct pair of metals, each of which will operate, *individually*, as if the other pair were not present; for if 1 and 2 be joined by a wire, they will operate as a distinct pair, and by a similar connexion between 2 and 6, they also will operate as a distinct pair, according to type 3, fig. 53. Now remove both of these connexions, and join 1 and 6, by a wire, as represented by fig. 23, and we have still two distinct pairs. The copper of number 1 and the zinc of number 2 form one pair, and the

copper of number 2 and the zinc of number 6 form another distinct pair, as decidedly as when they were respectively connected by a metallic wire; because the liquid between 1 and 2 forms a part of the circuit for the pair composed of the copper of number 2 and the zinc of number 6; and for the same reason, the liquid between number 2 and number 6, forms a part of the circuit for the pair formed by the copper of number 1 and the zinc of number 2 (see type 1.) But by type 4, we have two other pairs by this arrangement, and the four conspiring currents assist each other in producing the general effect.

Let us now introduce Nos. 3, 4, and 5, and by observing their relative positions in the arrangement, it will be found that there are just as many individual *operating* pairs, according to type 1, as there are cells filled with the liquid, which is one less than the absolute number of metallic pairs, represented by the figure; and, by contemplating the action of each adjacent pair individually, in the manner shown with respect to the two pairs already considered, as in type 1, it is immediately perceived that the whole operate in concert, as a series of pairs; and that the *general current* is in the same direction, as shown by all the four types.

Having thus shown the action of the battery, with reference to the individual pairs whose plates are *not in metallic contact with each other*, we have next to consider the action of those pairs, the plates of which are soldered together, and which form the partitions of the battery. Each individual pair of metals, thus considered, is referable to type 2, represented by fig. 52, when the two portions of liquid A and B, are united by the filled syphon S S, for if the liquid in any two adjacent cells of the battery, represented by fig. 23, were to be similarly united, the pairs of metal plates between them would immediately be brought into operation, and the electric current thus produced, would flow in the direction of the arrow and darts in figure 52.

Turning our attention again to fig. 23, we will suppose the pairs, number 1 and number 3, to be joined by a copper wire. By this means we, virtually, bring into play four pairs of metal, as decidedly, and for the same reason, as four are brought into play by uniting numbers 1 and 6, with only number 2 between them. By this arrangement we have a *compound* battery, the type of which is the fourth, and represented by fig. 52, when the compound arc S S has its zinc end immersed in the liquid A. If now we extend this miniature compound battery, by taking in another pair of metals, that is, by causing the conducting wire to unite number 1 with number 4, we shall then have number 2 and number 3 as intervening pairs, which will operate both *individually* and in *concert;* and also in concert with the copper of number 1 and the zinc of number 4; and for the same reason, every pair of plates in the interior of a battery, operate both individually and in concert with one another, and also in concert with the pair formed by the two extreme metals—the copper on one hand, and the zinc on the other.

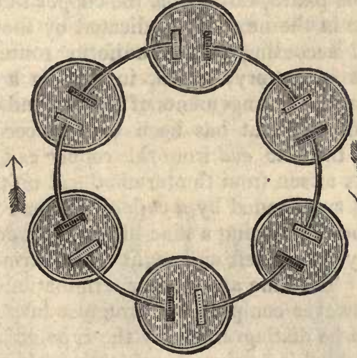
It being thus shown, that besides the action of the pairs by *direct* metallic contact, they also act with each other by *indirect* contact; we are led to understand that the metals operate in *two distinct capacities—exciters* and *conductors;* and by comparing the types with one another, and with the general arrangement represented by figure 23, we find that the whole of the *individual* currents operate in concert with one another, and that they constitute the *general* current, which flows through the conducting arc that joins the two ends of the battery.

The Cruickshank's battery, as usually constructed, has no metallic plates *exterior* to the liquid in the terminal compartments, the outer boundaries of those compartments being the cement which lines the wood. But it will be seen, by looking at fig. 23, that if the cell at the zinc end of the battery terminated with a copper plate, and that at the copper end terminated

in a zinc plate, another *pair* would be added to the series. These plates should be fastened in their respective places, and each furnished with a binding-screw for the reception of its conducting wires.

The battery invented by Dr. Wilkinson, fig. 28, page 65, has already been compared with the *Couronne des Tasses*, and its mode of action will be most easily understood by referring to fig. 54, which repre-

Fig. 54.



sents a horizontal section of the courronne des tasses. The figure represents six vessels, in each of which is a plate of copper and a plate of zinc. The former metal is represented by the deep shaded rectangle, and the zinc by the light shaded one. The copper and zinc in every two adjacent vessels, are in metallic contact by means of a conducting wire; but there is no metallic contact between the metals in any one vessel. Therefore the metals in this apparatus are similarly situated, with respect to one another, as in the Cruickshank's battery, when the circuit is closed, and by observing the arrows, which indicate the direction of the current, we find that it flows by corresponding routes in both pieces of apparatus.

Dr. Wollaston's battery, fig. 30, page 67, comes

next under notice. This apparatus does not differ from Dr. Wilkinson's in any one particular, excepting the mere bending of the copper round the bottom edge of the zinc plate, and continuing it upwards opposite the other surface. By this contrivance the electric fluid whilst traversing the liquid in each cell, flows both to the right and the left *from* the two surfaces of the zinc *to* the two portions of the copper surface which are adjacent to them. But the current through the plane of metallic contact, at the upper edges of the plates, flows *from* the copper in one cell *to* the zinc in the next, as indicated by the bottom arrow, and according to the uniform route in the other forms of battery, which, in fact, is a general law in Galvanic arrangements of every kind.

The difficulty that has been experienced in distinguishing the *zinc end* from the *copper end* of this battery, has arisen from the terminal end of the zinc plate being surrounded by a copper one, and the terminal copper embracing a zinc plate, as represented respectively by the left and right hand terminations in fig. 30. The zinc and copper terminations of any battery, however complex its structure may appear, will always be distinguished by the type afforded by the Cruickshank's battery, in which it is clearly seen that each pair of metals has its copper in one cell, and its zinc in an adjacent cell ; and, consequently, each *terminal pair* is in two adjacent cells ; and the metal in the exterior cell of the two, indicates the character of that particular end of the battery. If it be a copper plate, it is the copper or negative end or pole, but if the exterior metal of the terminal pair be zinc, that will be the zinc end or pole of the battery. In fig. 30, the right hand pair has the copper in the terminal cell, and its zinc in the next ; and in the left hand pair the zinc is the outermost metal, therefore the latter is the zinc end or pole, and the former is the copper end or pole of this apparently complex battery. Several batteries of modern invention have their metals in a cylindrical

form, and placed one within the other. This form partially conceals the distinction of the poles, but no difficulty can arise in ascertaining them correctly, by observing the rule already laid down.

For the display of certain classes of phenomena, some of these modern batteries have an immense superiority over those of the older forms; and I will now introduce such of them as may be required in some of the illustrations yet to be brought forward in these lectures.

About the year 1823, I formed Voltaic batteries of cylindrical copper vessels, and hollow cylinders of zinc. The copper vessels consisted of two concentric cylinders joined together by an annular bottom which was brazed to both. Fig. 55 is a representation

Fig. 55.

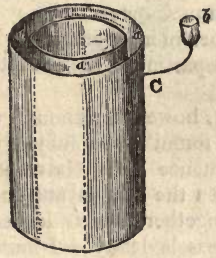
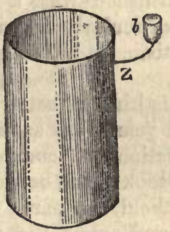


Fig. 56.



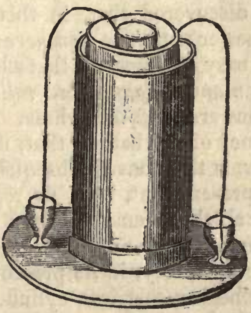
of the copper vessel, and fig. 56 represents the hollow zinc. The copper vessel had a sufficient space *d d d*, between the exterior and interior cylinders, to admit the introduction of the zinc without touching either of them; and the zinc was prevented from moving laterally, or sideways, by means of three pieces of cork, which were slit on the upper sides to receive the lower edge of the zinc, and fastened to it at equal distances from one another by means of cement. These corks answer the purpose of feet, on which they stood in the copper vessel, and thus

prevented metallic contact between the zinc and the bottom of the copper vessels. Each copper vessel held about a pint of liquid, which, for the charge, was usually a solution of nitrous acid. These miniature batteries were exceedingly convenient for electro-magnetic experiments, as the zinc cylinder could at any moment be removed from the copper vessel, and replaced when again wanted. Each battery was supported by a heavy wooden foot, from the centre of which rose a brass rod, which passed through the hollow axis of the copper vessel. The latter could be adjusted to any required height above the table by a moveable stage which slided on the rod, and when at the proper height was fixed there by means of a thumb-screw. Some of these batteries, however, had two brass loops soldered to the outside of the copper vessel, one above the other; and the brass rod passed through these loops, one of which was furnished with a thumb-screw. They will be more particularly described in my lectures on Electro-magnetism, in which department they are the most useful.

This kind of battery, however, although used for several years, was soon found to be subject to rapid dilapidation, in consequence of a Galvanic action which took place between the copper and the solder which held the parts together, which loosened the joints and made the vessels leaky. I found, also, that the soft solder by which the edges of the zinc cylinder were held together, and the zinc itself, formed a Galvanic pair, which gave rise to a local action, which assisted in destroying the zinc. In consequence of these inconveniences I was induced to alter the structure of the battery, and to exclude solder from the interior. This was accomplished by employing a porcelain jar for holding the exciting liquid, in which were placed a cylindrical scroll of sheet-copper, and another of zinc; the latter being the smaller of the two, was placed within the copper, and the two metals were insulated from each other by

means of a cylinder of brown paper. To the upper edge of each cylindrical scroll was soldered a stout copper wire, which bent downwards outside of the jar, and terminated in a cup holding mercury, which was fixed to the upper side of a wooden tray on which the jar stood. This form of battery, which is represented by fig. 57, I still use, and find it both cheap and useful.

Fig. 57.



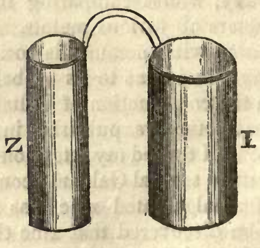
In the Bakerian lecture for 1826, Sir Humphry Davy, whilst comparing the relative electrical characters of various metals, stated that, "zinc amalgamated with mercury, is positive to pure zinc," without any allusion as to its probable beneficial employment in the construction of Voltaic batteries. Shortly after that lecture was published in the Philosophical Transactions, I turned my attention to that particular fact, and formed several Galvanic combinations, in which plates of amalgamated zinc was one of the metals; and I soon discovered that zinc thus treated would not only last much longer than pure zinc, but that a combination of the two formed a very efficient Galvanic pair. These discoveries were published in a pamphlet which appeared in the year 1830,* and in the same work

* The name of this pamphlet is "Recent Experimental Researches in Electro-Magnetism and Galvanism, &c."

I showed that a Galvanic pair consisting of copper and *rolled* zinc, has a much superior action to that exhibited by a pair consisting of copper and *cast* zinc. Indeed, I made several small batteries in which the metals were *cast* and *rolled* zinc. In the same pamphlet I have detailed several curious results which I obtained by experimenting with iron, which led me to the formation of Galvanic batteries with iron and amalgamated zinc, which I found were more powerful than when the latter metal was associated with copper. I also discovered that, in this capacity, *cast iron* has a superior action to *hammered or sheet iron;* hence, it was easy to perceive, that a battery consisting of *cast iron and amalgamated rolled zinc*, would be the most powerful of the whole. Such, indeed, is the excellency of this battery that, notwithstanding the several forms that have subsequently appeared, it yet stands pre-eminent, both as regards economy and action, in all those employments where *quantity*, without *high intensity*, is required.

The cast iron battery, in its present form, consists of a series of hollow cast-iron cylinders, about eight inches high and four inches diameter, to each of which is united, by means of a stout copper wire and solder, a cylinder of amalgamated zinc, as represented by fig. 58, in which I is the iron, and Z the amalgamated zinc. The iron cylinders are placed in porcelain jars containing diluted sul-

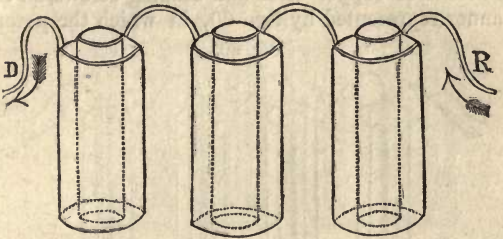
Fig. 58.



Published by Sherwood, Gilbert and Piper. Previous to the publication, Mr. Kemp, of Edinburgh, published a series of very interesting experiments, in which he employed a soft paste of the amalgam of zinc.—*See* "Annals of Electricity," vol. i. page 81. In most of the batteries that have been contrived since the publication of my pamphlet, *amalgamated* zinc forms one of the metals.

phuric acid, and each zinc cylinder is placed within the iron of the next jar in the series, as is represented by fig. 59. The jars holding the acid liquor are not

Fig. 59.



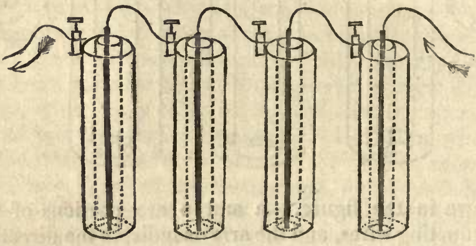
shown in the figure. R and D are portions of the conducting wires, and the arrows indicate the direction of the current when the circuit is closed. We shall have to employ this battery as we proceed in our electro-chemical illustrations.

Some time previous to the appearance of my pamphlet, M. Becquerel, of Paris, had taken advantage of the action of two dissimilar liquids and one metal, (as first shown by Sir Humphry Davy), by means of which he was enabled to form some chemical compounds similar to those formed by nature, and of which we shall have to say much more in another place.

In the year 1836, Professor Daniell brought forward a battery of large size upon nearly the same principle, employing two liquids and two metals. This formidable looking battery consists of a series of copper cylindrical vessels, usually two feet high, and about four inches diameter. In each copper vessel is placed another cylindrical vessel made of porous pottery ware. This latter vessel is of the same height as the copper one, but very narrow. It is charged with diluted sulphuric acid, in which is placed a rod of amalgamated zinc; and the annular space between

the porous vessel and the copper one, is filled with a strong solution of sulphate of copper. The rod of zinc in the first copper is connected with the second copper, and the zinc of the second copper with the third copper, and so on. The connexions are made by means of copper wires and binding screws, in the manner represented by fig. 60, in which the porous

Fig. 60.



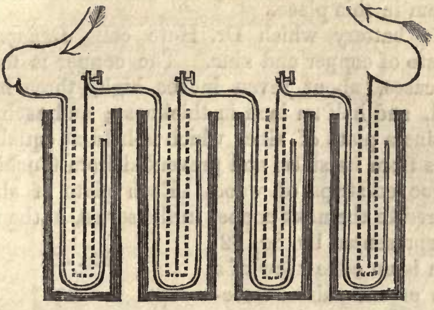
cylinders are represented by the dotted lines, and the zinc rods by the full straight lines between them.

Shortly after Professor Daniell's battery made its appearance, Mr. Mullins brought forward one, constructed of the same kind of materials, but with the zinc exterior to the copper. It consists of a series of porcelain jars, in each of which a cylindric scroll of zinc is placed, which is nearly the size of the interior of the pot. Within this zinc cylinder is placed a cylinder of sheet copper, surrounded by a piece of bladder. The space unoccupied by the zinc, between the bladder and the pot, is filled by a solution of sulphuric acid; and the interior space is filled with a solution of sulphate of copper. The pairs are connected in series by means of copper wires.

The most powerful battery that has hitherto made its appearance, is one contrived by Professor Grove. Its metals are platinum, and amalgamated rolled zinc; and the liquids employed are pure nitric acid, and diluted sulphuric acid. The platinum is immersed in the former, and the amalgamated zinc in the latter liquid. The metals and liquids are placed in rectan-

gular parallelopipedon pots, two of the vertical sides of which are broad squares, and the other two and

Fig. 61.



the bottom are comparatively narrow. Within the exterior pot, which is acid proof, is placed another which is porous. The latter pot holds the nitric acid and the platinum plate ; and the space which is unoccupied by this pot, holds the zinc and diluted sulphuric acid. The zinc sheet is amalgamated, and bends round the bottom of the porous pot, and presents itself to both of the square sides. An edge view of the zinc is pretty well represented by the shaded part c, of fig. 29, page 66. The connexions of the pairs with each other are the same as in all other batteries, with the exception of the mode of holding the plates together, which, in this battery, is by means of small brass vices with binding screws. Fig. 61 is a representation of a vertical section of three of the pots and their metals, as seen edgewise.

Mr. Smee has fitted up a battery, each compound metallic element of which consists of rectangular plates of amalgamated zinc, between which is a platinized silver plate of the same size, and parallel to them. The liquid employed is a solution of sulphuric acid.

Several batteries have lately appeared whose elements are charcoal and amalgamated zinc ; plumbago and amalgamated zinc, &c. But, with the

exception of the *Deflagrator,* invented several years ago, by Dr. Hare, of Philadelphia, it will not be necessary to dwell with descriptions of any more of them in this place.

The battery which Dr. Hare calls *Deflagrator,* consists of copper and zinc. The copper is formed into cases, about seven inches high, three inches broad, and half an inch in thickness; and each case contains a plate of zinc, which is held at equal distances from its sides, and prevented from touching it by grooved strips of wood. Each plate of zinc is soldered to the next copper in the series, in the manner represented by fig. 62, which is an edge view of a series of six pairs in section. The zinc plates z z z z z, reach downwards to the bottoms of the copper cases which are open at top and bottom, but not at any other place. One of the vertical edges of each zinc plate reaches just to the top of the copper case, but the other reaches much higher in order to meet the bent copper strap which is soldered to the upper edge of the next copper case. This form of the zinc leaves a triangular portion above the effective portions of the metals, as will be seen by looking at fig. 63, which is a representation of a copper case c, attached, by a strap, to the upper angle of the zinc plate z, the triangular part of which only is seen, the other part being hid from view by another copper case in which it is placed. A series of fifty pairs, with thin veneers between the cases, is fixed in a wooden frame, open at bottom and top: and three of these series are placed, endwise, in a ma-

Fig. 62.

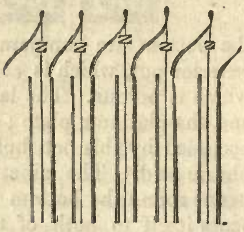
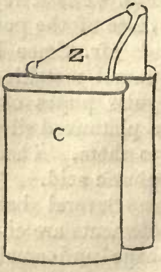


Fig. 63.

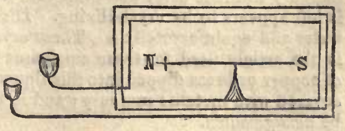


hogany trough, which holds the acid liquor. In order to throw the whole series of 150 pairs into, or out of, action at pleasure, a second acid trough is fixed to the other, in such a manner that their open tops may be at right angles to each other, forming a right angle all along the connected edges from one end to the other. The two troughs revolve on an axis which is coincident with their angle of connexion; the whole being supported by two upright posts, which are portions of a strong wooden frame, and through which the pivots pass. When one of these troughs has its open top horizontal, that of the other is vertical; so that by a quarter of a revolution the acid is transferred from one to the other; and as the Galvanic series is in one only, they may be brought into action, or thrown out of it, at pleasure, by these simple motions of the apparatus.

LECTURE IX.

Although our business in this course of lectures is not a display of Electro-Magnetism, there is a certain piece of electro-magnetic apparatus, called a *Galvanometer*, which is almost indispensible in Galvanic illustrations in the present state of the science. Its principal value consists in the facilities which it affords in ascertaining the *relative electric states* of two bodies; two metals, for instance, when united by wire and immersed in an acid or saline liquid. There are several shapes of the *galvanometer*, but that consisting of a hollow coil of copper wire, with a moveable magnetic needle within, is most in common use. Fig. 64 represents a vertical section of the coil with its contained needle,

Fig. 64.



which, when out of action, is to stand with its axis in the plane of the coil. The cups at the extremities of the coil-wire are for the purpose of holding mercury. If they be brass cups they are soldered to the wire, and their insides are amalgamated by means of a solution of nitrate of mercury;* but if they be wood, as is frequently the case, the wire passes through the bottom of each, and projects a little upwards within. The portion within being amalgamated forms an union with the mercury, which is afterwards placed in the cup.

Fig. 65.

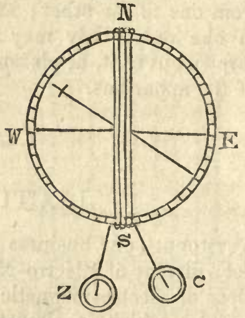


Fig. 65, represents the horizontal face of the instrument, which consists of a compass card graduated into degrees; the upper part of the coil, and the magnetic needle, which is represented in the figure as if deflected by the action of an electric current traversing the coil-wire. Although we cannot enter into an explanation of the theoretical principles upon which this instrument operates, until we arrive at our lectures on Electro-magnetism, it will be necessary, in this place, to point out one essential consideration in its practical indications. In the first place, then, since the needle when at rest assumes a magnetic north and south position, the instrument must be so adjusted that the needle may

* To prepare the nitrate of mercury, dissolve a portion of mercury in nitric acid, and evaporate the liquid till that which is left appears to be crystallizing. Dissolve this again in pure water and again crystallize. These crystals dissolved in water is the article used for these amalgamations. Any clean piece of copper or brass dipped into this liquor, becomes immediately covered with metallic mercury; and in this condition is said to be *amalgamated.*

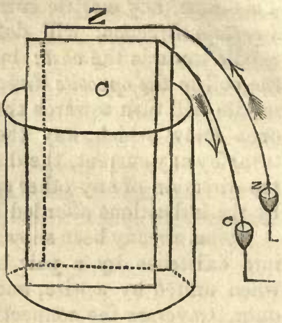
rest parallel to the wires in the upper part of the coil. This done, any electric current traversing the coil in a *certain direction*, will deflect the *north end* of the needle towards the *east:* but if the current traverses the coil in the *opposite direction*, the north end of the needle will turn towards the *west*. Hence, when we once know which way the north end of the needle turns by any current, the direction of which is known, the direction of any other current may be ascertained by the indications afforded by the deflected needle.

It has already been shown, that the current brought into existence by a pair of copper and zinc plates when united by a wire, and immersed in an acid liquor, traverses the connecting wire *from* the copper *to* the zinc. If, then, we employ this Galvanic pair as a standard of reference, and also mark the direction which the *north end* of the needle takes when these metals are connected with certain cups of the Galvanometer, we can, from these *standard data*, at any time ascertain the direction of an electric current which traverses the coil-wire, by the action of any other pair of metals.

Let us, for example, begin with the standard pair of copper and zinc. These plates may be of any size that we please, but when they are about two inches high, and one inch broad, they are as convenient as any. Having selected this size for the *standard pair*, we shall find it necessary, in some enquiries, to have all the other metals whose Galvanic actions are to be compared with the action of this standard pair, of precisely the same size and shape. But for the mere purpose of ascertaining the direction of the current produced by them, this nicety will not be required.

Having adjusted the galvanometer, we place the copper and zinc plates, c and z, in a small porcelain jar, holding an acid liquor, and connect their wires with the mercury in the cups c and z respectively, as represented by fig. 66. The needle is immediately deflected, and we find that its north end has taken a

Fig. 66.



westerly direction. Having ascertained this fact, we put the wires belonging to the copper and zinc into the other cups, so that they may change places. This done, the needle changes its position, having its north end now turned *easterly*.

Being previously aware that the current flows from the copper to the zinc through the connecting wire, we learn, from these last-performed experiments, that the needle's deflections are sure indicators of the direction of any current which flows through the coil-wire: and in order to facilitate our progress, whilst examining the Galvanic action of other metals, we must note down the position that the needle takes when the copper and zinc have certain connexions with the galvanometer, and fix upon these as *standard connexions* for this *standard pair* of metals. If, for instance, we fix upon the cup c, for connexion with the *copper* plate, and the cup z, for the *zinc* plate; we know that by these *standard connexions* the north end of the needle turns *westward*, which is its standard position for that *direction* of current.

If, now, we remove the copper plate, and introduce to its place a plate of brass of the same dimensions, the needle again takes a westerly deflection; hence, we conclude, that the current through the connecting wire is *from* the brass to the zinc, or in the *same direction*, as by a pair of copper and zinc. But it will be observed, when the needle is at rest in its deflected positions, by the two different pairs of metal, that it stood *farther* from the north by the copper and zinc, than by the brass and zinc; we therefore conclude that the copper and zinc produced the more powerful action of the two.

We next remove the zinc, and connect the brass plate with its cup z, and the copper plate with the cup c. The needle is again deflected westerly, but nothing like so far as with the brass and zinc. This shows that copper and brass form a Galvanic pair, but of the least power of any pair that can be formed of these three metals.

We will now replace the zinc, and with the cup c we will connect another plate of zinc. The result in this case cannot be predicted if both pieces be new, of the same size, and from the same sheet of metal. But the needle will immediately be deflected, which shows that a current traverses the coil wire; and, consequently, that the two pieces of zinc are in different electric states. If we do not disturb the metals in the acid liquor, the needle will slowly retire to the meridian line of the card; at which position it indicates the total absence of an electric current, and a consequent electric-equilibrium of the two pieces of zinc at that moment. But, by watching the needle a little longer, it will be observed to commence a movement in the opposite direction to that in which it was first deflected, This indicates another current in the wire, which flows in the opposite direction to the former; consequently the *relative electric conditions* of the two pieces of zinc have changed. This is frequently the case with two pieces of metal from the same mass, some of which will change their electrical characters several times in the course of a few minutes. Two pieces of iron are very subject to these electrical vicissitudes.

By experimenting with two pieces of well polished wrought-iron, both being of the same size and shape, some very interesting phenomena are produced, which are well worth the notice of every Galvanist. If one of these pieces of iron, already connected with the cup z of the galvanometer, be immersed in a solution of muriatic acid, in which the water is between twice and thrice the quantity of acid; and the other piece immersed shortly afterwards, and

connected with the cup c, the north end of the needle starts towards the west, showing a current to be running through the coil-wire, *from* the piece of iron last immersed. If, now, the first immersed piece be taken out of the acid liquor, and after a few seconds again immersed, the needle starts the contrary way, indicating a current *from* the last immersed piece. By removing from the acid liquor, and re-immersing first one piece of iron and then the other, several times, it is found that the current invariably flows *from the last immersed* piece. If one of the pieces be agitated in the liquor, the same effect is produced as by taking it out; so that by shaking either piece whilst the other remains undisturbed, a constant current may be kept up for a considerable length of time; and the piece which is shaken, and that which is at rest, will have the same electrical relation to each other as copper has to zinc, but the current produced is much more feeble than by the latter, or *standard* Galvanic pair.

We will now take two other pieces of metal, one of which is *cast zinc*, and the other *rolled zinc*, and connect them with the galvanometer; the cast-zinc with the cup c, and the rolled-zinc with the cup z. The acid liquor in the jar may either be the nitric, the muriatic, or the sulphuric. The needle's north end takes a *westerly* direction, indicating a current *from* the *cast* to the rolled piece; and as this current is steady for a long time, and an opposite current never produced by this pair, we infer that there is a constant electric relation with these two pieces of zinc, similar to that existing in the standard pair.

We now remove the cast zinc and replace it by the plate of copper. The needle is now deflected to a much greater angle than before. When it has come to rest we note its position on the card, or the degree to which the north end points. We now remove the rolled-zinc, and put the cast piece in its place. The needle becomes deflected as before, but when it has come to rest we find that the deflection from the

meridian line of the card, is not so great as when the copper and the rolled-zinc formed the Galvanic pair. From these results it is natural to infer that a Galvanic battery formed of copper and *rolled-zinc*, would be more powerful than a battery formed of copper and *cast-zinc*, which is absolutely the case. This fact was first announced in the pamphlet already noticed; and from that date, 1830, rolled-zinc has been more generally used than cast-zinc, which was the only shape in which zinc was previously employed in the construction of Galvanic batteries.

We may now try the effect of two equal pieces of rolled zinc, having previously amalgamated one of them.* If we connect the amalgamated piece with the cup c, and the pure zinc with the cup z, an electric current will traverse the coil-wire *from* the pure zinc to the amalgamated piece, as will be indicated by the needle's north end taking a *westerly* direction. This deflection is something considerable, and by trying each piece separately with a piece of copper, in the manner we proceeded with the two pieces of cast and rolled zinc, it is found that a pair of copper and *amalgamated zinc*, are much more powerful than a pair of copper and *pure zinc*. Hence it is, that amalgamated zinc is now employed in preference to pure zinc, in most of the modern forms of Galvanic batteries. These examples will be sufficient for giving you an idea of the usefulness of the galvanometer; but we shall again have recourse to this instrument in some of our subsequent illustrations, by means of which its value, as an implement of research, will become still more obvious.

Previously to the invention of the galvanometer, about the year 1822, philosophers had not the facilities they now possess for ascertaining the Galvanic relations which metals have to each other. Nor,

* If zinc be placed, for a few seconds, in a weak solution of sulphuric acid, and when removed, suddenly plunged into quicksilver, it immediately becomes coated with the latter metal. It is thus *amalgamated*.

indeed, had they any method whatever of making successful enquiries on the action of a *single* Galvanic pair, excepting in a few combinations, of which the action is considerably powerful. The only available indications for ascertaining the *direction* of the current, were, the *positions* which, after the decomposition of some chemical compound, certain elements took up in the circuit, with respect to the two *terminal metals* (platinum or gold), which conducted the current *to* and *from* the liquid operated on, in the manner already shown by the decomposition of sulphate of copper, by the action of a single pair of copper and zinc. But as many Galvanic pairs may be formed, whose action alone is too feeble to accomplish a separation of the elements of any known chemical compound, recourse was had to a *series* of these pairs, in the form of a *pile*, or of a *couronne des tasses*. The *relative powers* of various Galvanic combinations were ascertained by the quantity of oxygen and hydrogen gases that were liberated in a *given time* by the decomposition of water. Although these processes were attended with a great deal of labour, the ardour and perseverance of philosophers enabled them to overcome every obstacle that was met with in these researches; and Sir Humphry Davy, who took the most active part in them, ascertained, by his own experiments, the electrical relations of a considerable variety of bodies, both liquid and solid, when combined with each other in Voltaic pairs. To those combinations, which consist of two solids and one liquid, Sir Humphry gave the title of the *first order;* and those composed of two liquids and one solid, he called of the *second order*. The following tables, which express the Voltaic relations of both kinds of combinations, were constructed by that eminent chemical philosopher. The solids are called *perfect conductors*, and the liquids *imperfect conductors*.

FIRST ORDER.

Most oxidable Substances.	Less oxidable Substances.	Oxydating Fluids.
Zinc . . .	With gold, charcoal, silver, copper, tin, iron, mercury.	Solutions of nitric acid in water, of muriatic acid, of sulphuric acid, &c. Water holding in solution oxygen, atmospheric air, &c.
Iron . . .	With gold, charcoal, silver, copper, tin.	
Tin . . .	With gold, silver, charcoal.	
Lead . . .	With gold, silver. .	
Copper . .	With gold, silver. .	Solution of nitrate of silver and mercury. Nitric acid, acetous acid.
Silver . . .	With gold. . . .	Nitric acid.

SECOND ORDER.

Perfect Conductors.	Imperfect Conductors.	Imperfect Conductors.
Charcoal . . Copper . . Silver . . . Lead . . . Tin . . . Iron . . . Zinc . . .	Solutions of alkaline hydro - sulphurets, capable of acting on the first three metals, but not on the last.	Solutions of nitrous acid, chlorine, muriatic acid, &c. capable of acting on all the metals.

These tables were formed at a time when the general opinion of philosophers was, that it was essential in all Galvanic pairs, that the metal which occupied the place of zinc in the standard battery, be the *more oxidable* of the two; hence, in the table of the *first order* of combinations, the metals named in

the *left hand* column are more easily oxidized than those in the *second column*, which stand against them, and with which, respectively, they form a Galvanic pair. The liquids in which the pairs are immersed, are placed in the right hand column. In both tables the electric currents are supposed to proceed *from* those bodies which occupy the second column, *to* those which occupy the left hand column, with which they are respectively associated, in the same manner as *from* the copper *to* the zinc in the *standard battery*, which will be found convenient as a type of reference.

The doctrine above alluded to, and upon which these tables were founded, although it obtains in a considerable variety of cases, is by no means general, for there are many Galvanic combinations, now well known, in which the current flows, through the connecting wire, *from* that metal which suffers the greater degree of destruction by oxidation, *to* the other which suffers least of the two. And as these exceptions to the rule which the above doctrine sets forth, are essential data for the consideration of the theoretical Galvanist, and necessary to be known by every experimenter, I will bring forward a few specimens of them in this place.

A specimen of the action in question is afforded in a beautiful and striking manner by the Galvanic pair which is formed of two equal pieces of zinc, the one *pure*, and the other *amalgamated*. In the experiment already brought forward, it is seen that the *pure zinc* operates as copper in the standard battery. Now, by continuing that experiment for some time, and paying attention to the chemical action that goes on in the acid solution, we observe an immense quantity of gas rising from the surface of the pure zinc; but scarcely a bubble ascends from that which is amalgamated. The former piece undergoes rapid destruction, whilst that of the latter is comparatively slow. So slow, indeed, that it will outlast five or six pieces of pure zinc, combined with it in succession.

The deflection of the needle in these experiments, is exceedingly steady, even when the pure zinc is reduced to a mere film of trifling dimensions. "I have observed a deflection of more than 10°, for two successive hours, with two pieces, each exposing about one square inch of surface to the action of the acid solution, at the end of which time, the needle was perfectly steady at that angle, although the piece which operated as copper (in the standard battery) was nearly destroyed."*

By combining iron with amalgamated zinc, and immersing the pair in a solution of sulphuric acid, a powerful chemical action immediately commences on the surface of the iron, but scarcely any change can be observed on the surface of the amalgamated zinc; nevertheless, the electric current which the needle indicates, traverses the coil wire *from* the former *to* the latter metal.

These facts are sufficient to show the incorrectness of the views that were taken respecting Voltaic pairs of the *first order;* and I will now offer to your notice a few experiments by combinations of the *second order*, the results of which are directly opposed to those displayed by the combinations in Sir Humphry Davy's second table.

These experiments are made with the greatest facility by employing a galvanometer, and a vessel, divided by a bladder partition into two distinct watertight compartments, having the *same kind* of metal, but *different liquids*, in each compartment.† A vessel of this kind is easily made by sawing down the middle from top to bottom, a small cylindrical wooden box, the two halves of which, after stretching a piece of bladder over the open face of one of them, are to be held fast together, with the bladder between, by means of twine. Should any leakage be observed, it may easily be stopped by wax or cement.

* See my Pamphlet, previously alluded to, page 42.

† Ibid.

If we operate with two equal pieces of iron, and place diluted nitric acid in one compartment of the box, and water in the other, the metal which is placed in the acid solution suffers rapid oxidation, but that placed in the water scarcely any; yet the current through the coil wire is from the former to the latter piece.

"When a few drops of acid are mixed with the water, the electric energies become very much exalted, and the needle will frequently mark an angle of 75°, particularly if the *stronger* portion of the acid solution be not very feeble; and these energies seem to improve with an increase of acid in that portion of the fluid."* In the cell containing the stronger acid solution, the chemical action becomes quite violent, and the liquid is continually changing its character, from the rapid disengagement of fumes of nitrous acid and oxide, and the impregnation of the remaining liquid with dissolved oxide of iron, whilst that in the other chamber suffers but very little change. When *nitrous* acid is employed in place of the *nitric*, the phenomena are of the same character, but the current is more powerful.

The piece of iron which is placed in a solution of muriatic acid, or of sulphuric acid, and which necessarily suffers more rapid oxidation than another piece placed in water, invariably operates in combination with the latter, as copper with zinc in the standard battery.

When similar plates of copper are employed, and *dissimilar* solutions of either the nitric or the nitrous acid, we have first a momentary current *from* that plate in the feeble solution, to that in the stronger; but this current soon gives place to an opposite one, which indicates a change in the electrical relations of the two pieces to have taken place. This latter current is more powerful than its predecessor, and in consequence of its steadiness and

* "Recent Experimental Researches," the pamphlet before mentioned.

permanency, being the conclusive one, may very justly be regarded as the proper and essential current due to this combination.

When two similar plates of zinc are combined, and immersed in nitric or nitrous acid solutions, of very different degrees of strength, the currents indicated by the needle, are similar to those produced by the two pieces of copper. In strong and weak solutions of sulphuric acid, also, the piece immersed in the stronger solution, and, consequently, that which is suffering the more rapid oxidation of the two, invariably operates as copper in the standard battery. Hence we learn from all these experimental facts, that the *rule of Galvanic action* set forth in Sir Humphry's tables, although perfectly correct, with respect to the combinations which it exhibits, cannot be entertained as emanating from, or typical of, any universal law that exists in nature.

In an additional PART, which Professor Cumming, of Cambridge, has given to his translation of "A Manual of Electro-Dynamics," by M. J. F. Demonferrand, another table of the Galvanic relations of metals, in acid solutions, is given, differing, in some respects, from that of the *first order*, by Sir H. Davy. The following is Professor Cumming's table, by which is to be understood, that any metal in the series, when combined with any of those *above* it, has an electric relation to the latter, similar to that which copper has to zinc in the standard battery; but with respect to those metals which are *below* it in the list, it answers as zinc to copper in the standard battery.

Potassium.	Bismoth.	Tellurium.
Basium.	Antimony.	Gold.
Zinc.	Lead.	Charcoal.
Cadmium.	Copper.	Platinum.
Tin.	Silver.	Iridium.
Iron.	Palladium.	Rhodium.

I know of no philosopher on whose experiments, in this branch of science, more reliance can be placed than on those of Professor Cumming; and as far as

the pure metals are concerned, the above table is of essential value. But when the surfaces of the metals are amalgamated with mercury, their Voltaic relations do not, in all cases, follow in the same order. From the results which we have obtained, with a combination of pure zinc and amalgamated zinc, the *latter* would necessarily stand higher than the *former* in the scale, according to the order of arrangement in the above table; and from this it might probably be inferred, that because copper stands much lower in the scale than iron, a combination of copper with amalgamated zinc, would be more powerful than a combination of iron and amalgamated zinc. This, however, is not the case; for whether in a single pair, or in a compound battery, the latter combination is the more powerful of the two.

There have been from the earliest period of Galvanism to the present day, two diametrical opposite opinions entertained, respecting the source or cause of Galvanic action, and the facts advanced in favour of each opinion, have assumed the character of a distinct theory. Hence, there are now existing, what are called, two theories of Galvanism; one called the *electrical theory*, the other the *chemical theory*. The former originated with Volta, and supposes that every Galvanic phenomena emanates from the electricity which is developed by the simple contact of the bodies forming the series. The chemical theory, as has already been shown, originated with Creve and Fabroni, and is, at this time, advocated by several eminent men. It supposes that in every Galvanic pair, the action essentially depends on *a more rapid destruction* of that metal which corresponds with the zinc in the standard battery, than of that which corresponds with the copper; and it is on this principle that Sir Humphry Davy's tables were constructed.

The facts already shown are, however, sufficient of themselves, to refute every hypothesis that can be framed upon such a basis: and the electrical theory,

as Volta left it, although substantially correct in its general principles, does not apply them to those minute ramifications, or subdivisions of the action, essential to the propagation and maintenance of continuous electric currents.

With respect to the theory of the *dry electric column*, and the *water-charged* battery, I know of none that will account for the phenomena upon principles differing from those which have already been explained in these lectures. But to apply the innate electric forces to the production of continuous currents, we must first trace their influence in accomplishing those molecular changes which take place within the battery; and also those transportations of matter, independently of which, an electrical equilibrium must of necessity prevail, and a statical repose would ensue in every part of the Voltaic system. These considerations, however, we must defer for the present, for the purpose of making you acquainted with some other phenomena, which may be made available in illustrating the theory of the electro-chemical action both *within* and *without* the battery.

The decomposition of water by Galvanic action, in the experiments of Creve and Fabroni, was discovered some years previously to the formation of the pile by Volta. It occurred *within* the liquid which formed a part of the combination. But the discovery of the decomposition of water, *exterior* to the operating liquid in the combination, fell to the lot of Messrs. Nicholson and Carlisle; who, by means of Volta's pile, detected the hydrogen that was liberated at the negative polar wire, and observed the change which took place on the positive wire (which was brass), by oxygen combining with it. When platinum wires were employed for the terminals, neither of them suffered tarnish; and it was observed by these two philosophers, that oxygen was liberated at the positive, or *delivering* wire, and hydrogen at the *negative*, or *receiving* wire.

Since these discoveries were first made, a great

variety of apparatus have been invented for the purpose of exhibiting this interesting experiment to advantage. Fig. 67 is a representation of one of these pieces of apparatus. It consists of a narrow but very stout glass tube, closed at one end, and embracing a platinum wire, which is hermetically sealed in it. The wire reaches within the tube about two inches, and terminates in a small knob. The tube is filled with pure water, and its open end slightly closed by a cork, through the centre of which passes another platinum wire, with a terminal knob similar to the former. The knobs of these two wires being both within the tube are adjusted to less than a quarter of an inch from each other, and the tube is then inverted, and placed in a glass of pure water, and supported in a vertical position, as represented by the figure. That part of the lower wire which is exterior to the tube, ought to be well covered with varnish, to prevent loss of gas, which otherwise might rise from it.

Fig. 67.

When the apparatus is thus adjusted, the poles of the battery are to be connected with these platinum wires, and the water in the tube suffers decomposition. The liberated gases, hydrogen and oxygen, rise to the upper part of the tube, and displace the water, which descends in proportion to their accumulation. When the surface of the water has descended to below the knob of the upper wire, the circuit becomes opened, and the Galvanic action is consequently arrested. If, now, a spark from an electrophorus,* be transmitted from the upper to the lower knob, within the tube, the gases will explode, and entirely disappear, being re-united and again resumed the form of water. As the quantity of water thus formed is but very small, a vacuous space is left, for a moment, in the upper part of the tube, which is suddenly

* The Electrophorus is explained in my fourth lecture on Electricity.

re-filled with water, by the atmospheric pressure on the surface exposed in the glass vessel.

By employing two glass tubes, with a platinum wire in each, the oxygen and hydrogen gases, which are the results of the decomposition, can be collected separately. The two tubes are first filled with water, and then inverted and placed in a large wine glass, which also contains water, in the manner represented by fig. 68. The platinum wires in this arrangement ought to reach nearly to the open ends of the tubes, for by that means, the decomposition goes on much more rapidly than when they are shorter, and consequently not so near together. One of the wires B, is to be connected with the negative pole of the battery, and the other wire A, with the positive pole. It will soon be observed, that the gas collected in the tube B, occupies more room than that in the tube A, and in the course of a few minutes, you may pretty well ascertain their relative quantities, which, by measure, will be as two to one. These are, in fact, the relative proportions of hydrogen to oxygen, in the formation of water.

Fig. 68.

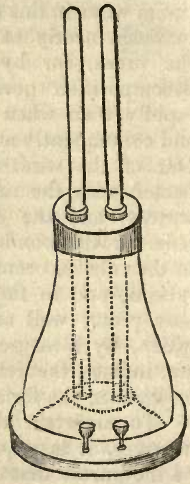
B A

To ascertain this fact by these experiments, however, it is requisite that the water operated on be the purest that can be obtained, and without any admixture whatever, otherwise the experiments would be vitiated. The glass tubes in which the gases are collected ought to be precisely of the same bore, and both graduated into inches and tenths, in order that their relative quantities may be accurately ascertained by mere inspection. When these things are strictly attended to, and the operation carried on as in the last experiment, the proportions of hydrogen and oxygen obtained, in their respective tubes, will be as above stated. And by collecting both gases in one and the same tube, and afterwards exploding them, as in the preceding experiment, it is found

that both disappear; and as no other inference can be drawn than that the gases have again combined, we learn, both from the *decomposition* and the *recomposition*, or, in other terms, from *analysis* and *synthesis*, the real constitution of water.

A more convenient, and at the same time, a more elegant form of apparatus for collecting the gases separately, is that respresented by fig. 69. It consists of a glass vessel, which resembles the frustrum of a cone. Prior to its being fitted up, it is open at both top and bottom. The opening at the bottom is in the shape of a neck which projects inwards, rising considerably above the level of the exterior of the base. This neck is filled up with a small bung, through which pass two strips of platinum foil, which rise about two inches above the cork, and terminate downwards in two concentric channels, which are formed round the centre of a wooden tray, on which the glass vessel stands. These channels are filled with mercury, each portion of which communicates with a brass cup, by means of a wire which passes under the tray. These cups are fixed to the edge of the tray, as seen in the figure, and are filled with mercury, for the purpose of communication with the connecting wires of the battery.

Fig. 69.



The upper end of the glass vessel is closed by a brass cap, having two poles for the reception of two tall glass tubes, both of which are closed at their upper extremities, but open at bottom. When in their places, each covers one of the platinum terminals which rise from the base. The tubes are furnished with *screw ferrules*, by means of which

they are screwed into the holes in the cap, and kept steady in their places.

When this instrument is employed at the lecture table, the water operated on is usually mixed with a little sulphuric acid. The glass vessel is first nearly filled with the liquid, and when the tubes are firmly screwed in their places, the apparatus is inverted for the purpose of filling them; which done, the glass is placed on its tray, and the battery connexions made with the cups. The upper part of the large glass has a small perforation for the purpose of allowing the air to escape, whilst it fills with the water that is forced out of the tubes, by the gas which collects in them.

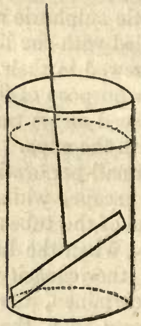
When the full extent of the power of a battery, in the capacity of decomposing water, is to be ascertained, the platinum terminals must be much larger than those we have hitherto employed, and placed much nearer together. Apparatus suitable for this purpose will be brought forward in our concluding lecture of this course.

Some very interesting experiments on the electro-decomposition of water, are made by modifying the apparatus of Fabroni. Fig, 70 is a neat little apparatus, contrived by Mr. Silvester, for this purpose. It consists of a small glass jar, nearly filled with water, to which a very small proportion of sulphuric or muriatic acid is added. Through a cork which fits the mouth of the jar, passes a short zinc wire, and also a longer wire of silver, or copper. The lower part of the latter c s is turned upwards, and the upper part is bent at right angles, as seen in the figure. When the upper part of the copper wire is turned away from the zinc, the latter only, gives off gas, but when the two wires are brought into contact, by pressing the horizontal part of the copper against the zinc, a Galvanic pair is formed, and hydrogen in abundance rises from every part of the copper wire.

Fig. 70.

A very instructive experiment is made by employing amalgamated zinc instead of that which is not so treated. Fig. 71 represents a glass jar nearly filled with a limpid solution of sulphuric acid. In the jar is placed, in a sloping position, a strip of amalgamated rolled zinc, which, not having the power to accomplish decomposition, every thing in the vessel remains perfectly tranquil. I now introduce a copper wire to the liquid, which is also inert whilst separate from the zinc. But on pressing it down, so as to bring the two metals into contact, the Galvanic pair is formed, and hydrogen ascends from every part of the copper wire below the surface of the liquid, but not a single bubble of gas escapes from the surface of the amalgamated zinc.*

Fig. 71.



If, instead of a straight copper wire, we employ one formed into a long spiral, like a large cork-screw, and press its lower end against a piece of amalgamated zinc, laid in the bottom of the jar, the effect is much more striking. The gas ascends in the fluid in the form of a cylindrical pillar, increasing in density from the bottom upwards to the surface. By raising the wire from the zinc, the Galvanic chain is broken, and every trace of chemical action immediately lost. And by thus uniting, and disuniting the metals, alternately, we create, and annihilate, chemical action at pleasure. This is one of those instructive experiments from which we learn that chemical action is due to electric agency, and strikes at the root of the chemical hypothesis of Galvanism, for every feature of it disclaims a chemical origin.

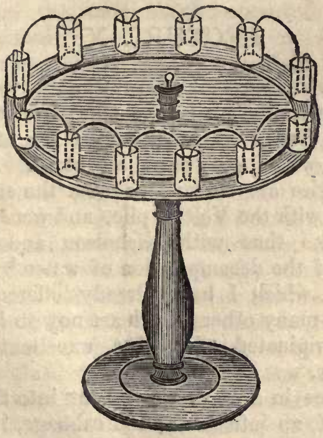
Another very imposing variation of this interesting

* This experiment, and the two following variations of it, were first published in my Recent Experimental Researches, &c.

experiment is accomplished by employing a *flat* spiral of copper wire, having the two end portions straight, and proceeding in opposite directions from the centre of the spiral, and at right angles to its plane. Fig. 72 will give an idea of its form. The lower portion c, from the point to the spiral, is to be well covered with varnish, cement, or bees' wax, and the point quite bright, or amalgamated. The upper part of the wire answers the purpose of a handle. When the point c is pressed upon the amalgamated zinc at the bottom of the jar, (fig. 71,) gas is immediately liberated from the water at every part of the spiral portion of the wire, and ascends in a dense cylindric cloud thence to the surface of the liquid, whilst the lower portion remains as tranquil and limpid as if no such process were in operation in the vessel.

Fig. 72.

Fig. 73.



The action of a series of several pairs of copper and amalgamated zinc, arranged in regular order of

sequence, may be very beautifully exhibited by a *couronne des tasses*, of which fig. 73 is a representation. It consists of twelve small glass tumblers or jars, arranged in a shallow circular channel, which margins the upper surface of a round mahogany table, twelve inches in diameter. The boundaries of the channel prevent the glasses from slipping off the edge of the table. These glasses are furnished with twelve Voltaic pairs of copper and amalgamated zinc wires. The liquid employed is a limpid solution of sulphuric acid, which has become cool after mixing. When eleven only of the metallic pairs are in their proper places, the extreme glasses will be the poles of the arrangement; and as the circuit is not closed, no chemical action takes place in any of the glasses. But the moment the circuit is completed, by introducing the twelfth pair of wires, gas is liberated at every copper wire in the series, but none rises from the amalgamated zinc.

LECTURE X.

PERHAPS there is no philosopher to whom we are more indebted for leading us to the true path of Electro-chemistry, than Dr. Cruickshank, the inventor of the battery which still bears his name. Several of his discoveries are coetaneous with the earliest that were made with the Voltaic pile, and were published at the same time with Nicholson and Carlisle's discovery of the decomposition of water.* Some of those facts which I have already offered to your notice, and many others which are now to be brought forward, originated with that excellent chemical philosopher.

We place in a glass tube, bent into the form of the letter V, an infusion of red cabbage, in which a

* Nicholson's Quarto Journal for July, 1800.

few crystals of Glauber's salts (sulphate of soda) have been dissolved, and support it in a wine glass, as represented by fig. 74. To the liquid in each branch of the tube, is introduced a platinum wire, reaching nearly to the bend. When the upper extremities of these wires are connected with a Cruickshank's battery of fifty pairs of small plates, a decomposition of the water, and also of the salt immediately commences, and in a short time the liquid assumes two distinct colours. That portion in which the *delivering terminal* is placed, appears red, denoting the presence of acid, and that in the other branch of the tube becomes green, and indicates the presence of an alkali. Hence the sulphate has suffered decomposition and its constituents have taken up certain determinate positions in the circuit. The sulphuric acid has assembled at the *positive* or *delivering* terminal, and the soda at the *negative* or *receiving* terminal metal.

Fig, 74.

If, instead of the sulphate of soda, the sulphate of potash had been employed, the results of the experiment would have been similar. The sulphuric acid would still be found at the *delivering* terminal, and the alkali at the *receiving* terminal. Or if, to the infusion of red cabbage, a little sulphuric acid were first added, which would produce a red liquor, and afterwards some liquid ammonia, till a neutral blue liquor was obtained. On submitting this neutral liquor to the Galvanic action in the bent tube, the results would be as in the two preceding cases.

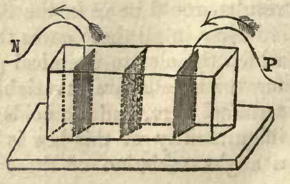
Now in all these cases there is an obvious law by which the electro-chemical phenomena are displayed, for the alkalis are invariably found at the negative terminal wire, and the acids at the positive one. The immutability of this law is beautifully illustrated by a slight variation of these experiments; which is

done by merely reversing the battery connexions with the platinum terminals after the first results are obtained. When the first results are very perfect, there is at the bend of the tube a well defined plane of demarcation between the red and the green portions of the liquid; which, as soon as the battery connexions are reversed, begins to fade, and soon vanishes altogether; being obliterated by the mixture of the two colours, which is occasioned by the acid and alkali travelling in opposite directions, and exchanging places in the bent tube. This transfer of the acid and alkali is completed in the course of a few minutes; and, as was before observed, is a striking illustration of the law of electro-chemical action. We will, however, proceed with a few other experiments in which this beautiful law is still further manifested.

We may now operate on those compounds which are insoluble in water, and still we shall meet with similar results. If, for instance, we place finely pounded sulphate of baryta in a portion of the infusion of red cabbage, and operate on the mixture in the bent tube, fig. 74, the baryta, which possesses alkaline properties, will be collected in that branch which contains the negative or *receiving* wire, as will be understood by the liquid becoming green; and the sulphuric acid, which was the other constituent, assembles around the positive or *delivering* wire, and there converts the liquid into a red colour.

A very convenient apparatus for exhibiting the results of electro-chemical decompositions, is represented by fig. 75. It is a rectangular box made of plate glass, and separated into two compartments by means of a gauze or buckram partition. We place in this box a solution of idoide of potassium, with a little

Fig. 75.



starch mixed with it, and a strip of platinum in each compartment. To each plate of platinum, (which in this case are the *terminal metals,)* is soldered a copper wire, for convenience of connexion with the battery, and if the wire P be connected with the *positive* pole, (zinc end) and the wire N with the negative pole, (copper end) the platinum belonging to the former will be the *delivering terminal,* and that attached to the wire N the *receiving terminal, to* and *from* the liquid, respectively. The decomposition takes place immediately, as may be understood by the liquid about the delivering terminal turning slightly of a brown colour. This is occasioned by the presence of iodine, which is liberated from the dissolved salt, and which becomes so abundant in a short time, as to cause a dense brown cloud around the delivering terminal, and, eventually, the whole of the liquid in that compartment of the glass box becomes deeply coloured by it. In the other compartment the liquid continues unchanged, and nothing remarkable appears but a liberation of hydrogen, which rises from the *receiving terminal metal.*

In this experiment, as well as in many others, a *secondary* action takes place; and as these secondary actions cannot be more simply exemplified than in the present case, we will avail ourselves of it as a *type* by means of which others may be understood.

The iodide of potassium is a compound, consisting simply of iodine and potassium. The first, or *primary* Galvanic action accomplishes a separation of these two elementary bodies; and the iodine is drawn to the *positive* or *delivering* terminal, and none of it is to be found in the other compartment of the apparatus. The potassium, however, is drawn to this latter compartment; and the reason that it is not found there in its natural character as a metal, is simply this: as fast as it arrives at the receiving terminal, it is assailed by the oxygen of the water, which, being in a different electrical state, unites with it, and the result of this union, or secondary

action, is potassa. The hydrogen, which the oxygen has deserted, finding no other body with which it can unite, quits the liquid in the shape of gas.

We will now operate on another anhydrous salt, the chloride of sodium, or the common salt of the table. This salt consists of a metal called sodium, and chlorine, which is a gaseous body. In order to show a *secondary* action, whilst operating on this salt, we employ a solution of indigo in sulphuric acid. The sulphate solution of indigo being well diluted with water, we put into it a large spoonful of common salt, and place it in the partitioned glass box, fig. 75. The sodium in this case, as in the preceding one, proceeds to the cell in which is the *receiving terminal*; and a *secondary* action taking place between it and oxygen from the water, the formation of soda is the consequence, and the hydrogen thus deserted flies off in its gaseous state. Whilst these things are going on at the negative terminal, the chlorine which has been separated from the sodium assembles around the *positive* or *delivering* terminal, and immediately sets to work upon the indigo, the beautiful blue colour of which it gradually and effectively destroys; and, if time be permitted, every trace of colour in that particular chamber of the box, will entirely disappear, but the other portion of liquid suffers no apparent change.

It would appear from this last series of experiments, that the alkalis are not formed until their metallic bases have arrived at the negative terminal, and, consequently, the solutions of those alkalis, which must be subsequent to their formation, is a tertiary event. Taking this view of the process, we can easily understand, that in all cases where the solution of an alkali is one of the ultimate results of electro-chemical decomposition, the liberation of the alkaline base is the *primary* result, the formation of the alkali is the *second* result, and the solution of this salt is the third.

The same law holds good in the decomposition

of those salts whose metallic bases do not enter into new associations during the Galvanic process, for in all cases, the metals which are liberated, assemble at the *negative* terminal, and the acids with which they were combined, as uniformly assemble at the *positive* terminal. In illustration of this fact, a few experiments may here be necessary.

Into a solution of the sulphate of copper I introduce two platinum wires, which are the *polar* or *terminal* wires of a battery. In a few seconds the receiving terminal will be covered with copper, but none will appear on the *delivering* terminal. We now reverse the battery connexions, making that wire which before *received* the current from the solution, now *deliver* the current to it, and that which before was the delivering wire, now be the receiving one. Permitting the action to proceed a few seconds, and then examining the two wires, we find, that the copper has entirely disappeared from that on which it was first deposited, and that the other is now cased with copper.

We proceed in a similar manner with a solution of the nitrate of silver, employing gold wires instead of platinum ones. The *receiving* gold wire is soon covered with metallic silver, which in time shoots into beautiful needle-like crystals, but none appears on the *delivering* wire. By reversing the wires with the poles of the battery, the silver soon leaves that on which it was deposited by the former part of the experiment, and the other receives a silver coating, with the shining needles as before. These needles seem to be produced to the greatest perfection, when the terminals are silver wires. Gold wires are employed in the reduction of silver and other white metals, on account of the colour being a better contrast to them than platinum; but in some instances, copper terminals answer very well. If, for instance, we operate upon a solution of the muriate of tin, or the acetate of lead, the result of the experiments is very conspicuous in a very short time, by that

portion of the *negative* or *receiving* copper wire which is below the surface of the liquid becoming covered with the tin in the one case, and brilliant spangles of lead being formed around it in the other. By adding a little vinegar to the acetate solution, the reduction of the lead is much facilitated.

We now employ a solution of the muriate of gold, and platinum terminals. The auriferous salt immediately suffers decomposition, and the *receiving* terminal wire becomes gilt with the liberated gold; but no change is observed on the positive or *delivering* wire. If, now, we change the battery connexions, the gold soon quits the wire on which it was deposited, and the other receives a similar portion from the liquid.

Besides the observations which have been made during the progress of these electro-chemical decompositions, there are still some others to be offered which are well worthy of attention. You will have observed in some of these experiments, that a considerable quantity of gas escaped from the *positive* or *delivering* terminal, though never so copiously as from the other metal. This is one of the consequences of employing too much battery-power, by means of which a portion of water became decomposed. When the battery has not too much power, the salt in solution is the only article that suffers decomposition; under which circumstances, no gas is seen at the delivering metal. This is one of the most important considerations in the arts of *electro-typing*, *electro-silvering*, and *electro-gilding*; for if the battery employed in any of these processes be sufficiently powerful to decompose the water, the hydrogen which is liberated at the negative terminal interferes with the deposition of the metal, and prevents it from lying in a compact form and with a smooth surface.

Another phenomenon which takes place, is the corrosion of the delivering terminal, under some circumstances. When a metallic salt is decomposed,

and no oxygen gas escapes from the *positive* or *delivering* terminal, that gas which is liberated from the salt enters into an union with the terminal, and with it forms an oxide, which in many cases is soluble in the liquid of the solution.

This is a fortunate circumstance in the arts above alluded to, because the liquid becomes charged with new supplies of metal on one hand, at precisely the same rate as it parts with it on the other. Therefore, the *delivering terminal* in those processes, should always be of the same kind as that of the salt in solution. In the electro-type process, it must be a copper terminal, and in the silvering and gilding processes it must be silver and gold respectively.

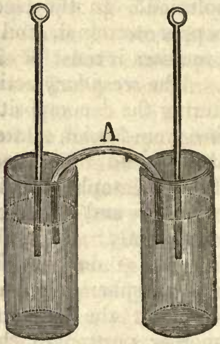
The *secondary* actions which frequently take place during the decomposition of water, which is not quite free from foreign matter, were first noticed by Cruickshank, and were amongst his earliest discoveries. This philosopher obtained nitric acid at the *positive terminal*, and ammonia at the *negative* one, and very justly supposed that the former originated from an union of the oxygen with the nitrogen of atmospheric air which the water held in solution; and that the ammonia resulted from an union of another portion of the nitrogen with the liberated hydrogen.

In the experiments of some other philosophers, muriatic acid and soda were formed under circumstances where it was supposed the constituents could not have existed; for instance, in the decomposition of pure water. And it was not until the masterly investigations of Sir Humphry Davy were announced, in the year 1806, that the true source of these compounds became properly understood. In a paper that was read towards the close of that year, Sir Humphry showed by several excellent experiments, that not only might these products result from the most trifling impurities in the water operated on, but that the vessels which held the water would suffer decomposition by the Galvanic process, and yield up

elements which, by secondary actions, would give the observed results.

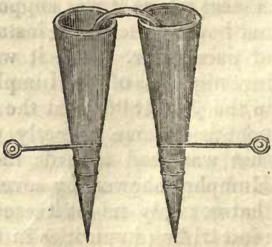
In some of these experiments, Sir Humphry employed small cylindric vessels made of agate, and the results were various, but the generality of them indicated impurities in the water, which had either existed previous to the Galvanic process, or were taken up from the vessels during the time. Two of these vessels were generally used at the same time, the two portions of liquor in them being united, by a bundle of moistened asbestos A, as represented by fig. 76. The wires with rings at their upper extremities, were of platinum or gold, and were the terminals for the two poles of the battery. When the two portions of water were tested, after being subjected to the Galvanic process for many hours, an acid in one vessel, and an alkali in the other, was an usual, though not a constant result.

Fig. 76.



When two portions of the purest water that could be procured were placed in two vessels of gold, in the form of cones, as represented by fig. 77, the results were still unsatisfactory whilst the water operated on was exposed to the atmosphere, and it was not till this persevering chemical philosopher thought of surrounding the gold vessels, with their contents by an atmosphere of hydrogen gas, that he was enabled to prove that the formation of these compounds was not due to new

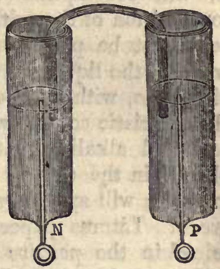
Fig. 77.



forms of the constituents of the water. By this mode of experimenting, however, Sir Humphry succeeded in decomposing the water without the production of any new compound whatever, and thus set at rest a question, which had for some years previously, puzzled almost every philosopher in Europe.

From the accuracy of the views which Davy generally took respecting electro-chemical action, and the immense range of apparatus he had at command, his experiments were generally attended with the happiest results; and his inventive genius enabled him to contrive those forms of apparatus which gave to his experimental productions the most imposing effect. By introducing two or more vessels into the circuit, connected with asbestos, as in figs. 76 and 77, acid and alkaline matter, and other compounds, are collected in the different vessels, perfectly distinct from each other, and may be kept separate for examination as long as the operator pleases.

Fig. 78.

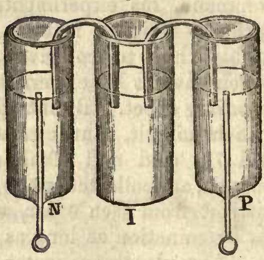


If we place pure water in the vessel N, fig. 78, and muriate of lime and water in the vessel P, and connect their contents by moistened asbestos, as shown in the figure, and also the platinum wires P and N, with the *positive* and *negative* poles, respectively, of a battery of even moderate power, the lime soon begins to quit the muriatic acid, and travels over the asbestos to the vessel N, but the muriatic acid remains in the vessel P. If the muriate of lime be first placed in the vessel N, and pure water in the vessel P, the lime will remain in the former vessel, and the acid will find its way to the latter. Therefore it is of no consequence in which vessel the muriate be placed, the final result is invariably the same.

If instead of the muriate, the sulphate of lime,

or the carbonate of lime, be powdered, and mixed with water in one of the vessels, the acid and lime still take up their respective positions in the circuit, being found at the *positive* and *negative* terminals respectively, which shows that lime is one of those bodies which have a natural tendency to be placed in the same part of the circuit, as hydrogen and the metals invariably proceed to.

Fig. 79.



If we employ three vessels, and arrange them as in fig. 79, and in one of the exterior vessels we place pure water, and in the other a solution of the sulphate of potash; and in the centre vessel an infusion of litmus. The battery, when connected with the terminals P and N, will accomplish decomposition of the salt, in which ever of the exterior vessels it be placed; and the acid and alkali will traverse the liquid in the centre vessel in opposite directions, without interfering with each other. The characteristic colours which indicate the presence of acid and alkaline matter, will be beautifully displayed in the central vessel I, one half of the liquor in which will appear red, and the other half a heavy green. Litmus paper immersed in the liquid contained in the *positive* exterior vessel will turn red, and turmeric paper will indicate the presence of free potash in the other exterior vessel.

From what has already been brought forward it will appear obvious, that in all cases of electro-decompositions there exists an immutable law by which the whole of the phenomena are brought into existence, and it will readily occur to the experimentalist, that these facts are mere samples of the immense number that are within his reach, and which he may vary in many ways.

LECTURE XI.

By contemplating the facts already before us, upon the strict principles of electricity, we are immediately struck with the analogy which is presented when these are compared with the results of Leichtenberg's experiments, in which dissimilar particles of matter are separated from each other by electric forces. In those experiments, the different kinds of matter proceed to differently electrized surfaces, which is precisely the case in all Galvanic decompositions; and their determined positions with respect to those surfaces are as uniformly manifested by the one process as by the other. Moreover, when by the Galvanic process the result is simply a decomposition of some compound of two elements only, it is a precise counterpart to the separation of the powders in Lichtenberg's experiments; and a more exact analogy does not exist in any two cases within the boundaries of experimental science. Therefore, since we are perfectly aware, that the separation of the particles of matter in the one case is accomplished by electric forces, we very naturally infer, that the separation of dissimilar matter by the other process, is also due to electric forces.

By viewing the results of simple electro-decompositions in this light, they may be very easily understood, since it is only necessary to be borne in mind, that each species of matter having a *specific degree* of electric tension, from its natural peculiar susceptibility of becoming charged, will, whenever a group of other bodies are sufficiently near, invariably tend to move towards that, the electric tension of which differs most from its own; and whenever an opportunity presents itself, the two bodies will come into the most intimate union with each other.

I am not aware of a better illustration of this fact than that afforded by a pith ball, suspended by a silken fibre, at equal distances from the balls of

three circumjacent Leyden jars of equal size, but charged to different degrees of intensity. The ball, as would be expected, invariably proceeds to the highest charged jar; but when it has arrived at the same degree of intensity as that of the ball of the jar, it quits the latter, and flys to the jar which has the lowest charge of the three.* In Leichtenberg's experiment, although the powders do not quit the electric surfaces to which they are first drawn, they select and proceed to those surfaces upon the same principles and according to the same law, as the ball selects and proceeds to one particular jar, at each trip, in preference to any of the others.

The red lead and the sulphur are in different electric conditions; and, consequently, each selects that electrized surface of the resinous cake (fig. 14, page 48.), whose tension is the most remote from its own. By keeping in view this simple, but universal law of electric action, whilst contemplating electro-decompositions of *simple compounds*, there can be but little difficulty in understanding the process. If, for instance, we select the iodide of potassium, and operate upon it with the electric machine, its two elements, iodine and potassium, become separated; and, like the red lead and sulphur, each body selects, as it were, and proceeds to, that *terminal wire* whose electric tension is the most remote from its own. The same reasoning is also applicable to the decomposition of water; the constituents of which, being in different electric conditions, travel to those respective terminals between which, and themselves, the electric force is greatest: and the same law holds good in the electro-decomposition of every compound, whatever may be the number of its constituent elements. But, as is the case with iodide of potassium, the *primary* effects

* This is a beautiful and very instructive experiment, when the intensities of the three jars are considerably different from one another. Their balls ought to be placed at equal distances from one another, and all in the same horizontal plane, and something higher than the suspended pith ball, when hanging quiescent in the mid-space.

are frequently concealed by the products of *secondary* actions.

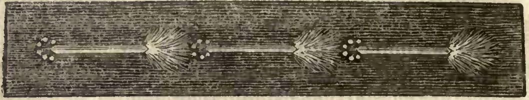
There appears, however, to be an opinion entertained, by some persons, that a series of conducting bodies in contact with one another, cannot be in different electric conditions at one and the same time; or in other words, they cannot, *individually*, be electro-polar. Hence, in a *continuous*, or *closed* electrical circuit, whether belonging to the machine, or to the Galvanic battery, every part must be in the same degree of electric tension, under which circumstances, the cases which we have here pointed out would not be analogous, and the law by which the phenomena are displayed in Leichtenberg's experiment, would not be applicable to electro-decompositions. The idea, I believe, originated with Mr. Singer, whilst attempting to controvert some peculiar views of Sir Humphry Davy. It would be difficult to say from what train of reasoning Singer arrived at this view of an electric circuit, more especially as he was one of the first electricians of his day, and has, in his treatise on the subject, described some experiments, the phenomena of which, not only cannot be explained upon the principles he advocated, but are the most palpable evidences opposed to them.

In my sixth lecture on Electricity, page 80, I have pointed out an universal law, which will assist us materially in this place. "Whenever a body is *delivering* the electric fluid to another body, the former is *electro-positive* to the latter; and, as the terms *positive* and *negative* refer to the relative *intensities* only, without any reference whatever to the relative *quantities* of fluid that the bodies absolutely contain, it is obvious, that in all cases where a transference of the fluid takes place, the *delivering* body must be more intensely charged than the receiving one." In illustration of this law, I have advanced the following experiment.

"We arrange a series of insulated pointed wires, in the manner represented by fig. 80, having one

end of the series directed to the pointed wire in the

Fig. 80.



end of the prime conductor, and the remote extremity of the series in the opposite direction. The whole series of points will become luminous the moment that the machine is put to work. The point projecting from the prime conductor, and the *remote* point in every wire will throw out a brush of electric fluid into the vicinal air, and the nearest points will be tipped with electric stars, indicating that those points are occupied in receiving fluid at the same time." Hence every wire in the circuit is both *receiving* and *delivering* fluid *to* and *from* the vicinal air; and, according to the above law, not only are those wires *electro-polar*, but every individual portion of intervening air must, of necessity, be *electro-polar*, being, relatively, *positive* and *negative*, at the *delivering* and the *receiving* surfaces, respectively.

If now we arrange in a line several small piles of paper, well soaked in a strong solution of iodide of potassium, on a long slip of glass, placing upon every adjacent two, a wire of platinum, so that its extremities may just rest upon the edges of the paper without touching the next wire in the series, we shall have an opportunity of making an experiment somewhat similar to the last one. And if we cover the ends of the wires by continuing the piles a little higher, we shall have an arrangement of alternate *metal* and *liquid*, as decidedly as that of *metal* and *air* in the former case. And when presented to the prime conductor, the electro-polarizations are similar in both cases. Every wire has both a *receiving* and a *delivering* point, *to* and *from* the liquid, and the result is a decomposition of the salt, the constituents of which become arranged in the circuit according

to the same law that regulates the phenomena in Leichtenberg's experiment.

We may now form a similar arrrangement, and place it between the polar wires of a Voltaic battery. The result is precisely the same as by operating with the machine. The liberated iodine is found at those extremities of the wires which are most remote from the *positive*, or zinc end of the battery, but none is found near to the other ends of the wires.

The experiment of Mr. Singer, before alluded to, is similar to the last one. A series of platinum wires are arranged in the axis of a long glass tube, by the assistance of cubical pieces of cork, in the manner represented by fig. 81. The ends of the

Fig. 81.

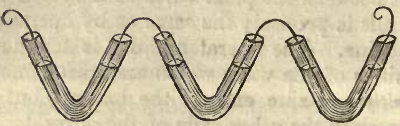
tube are each filled with a cork, through which a platinum wire passes, and when the tube is filled with water, and the terminal wires of the series attached to the poles of a battery, the whole arrrangement becomes polar. Every wire has both a *receiving* and a *delivering* extremity, and oxygen is liberated at the latter, and hydrogen at the former.

If the tube be filled with an infusion of red cabbage, rendered blue by proper proportions of sulphuric acid and liquid ammonia, the polar actions of the series of wires become remarkably well shown, by the red and green colours produced at their *positive* and *negative* extremities, respectively. When the tube is filled with a solution of any of the metals, each individual wire collects the liberated metal at its *receiving* termination, but none is found at the delivering one.

With a straight glass tube, the gases which are liberated, accumulating at the upper side, press upon the liquid and force a portion out of the tube, and sometimes force out the cork also. This inconvenience is avoided by having a series of bent tubes,

with platinum wires, joining their liquid contents, and arranged as represented by fig. 82. The wires

Fig. 82.



in this apparatus, assume their respective electro-polaraties, as precisely as by any other arrangement; and each pole performs its peculiar function accordingly.

When six or eight of these platinum wires are arranged in one series, and the bent tubes contain a solution of copper, tin, or zinc, the deposited metal being in close contact with one end of each platinum wire, a series of Voltaic pairs become formed by the two metals, and the arrangement of these metals, in this secondary battery, being in the opposite direction to those in the *primative* battery, the two operate against each other. This checks the action of both; and, in some cases, the action of the *secondary* battery, so far counteracts the force of the *primative* one, as to reduce it to below the requisite degree for carrying on the decomposition. An ingenious Prussian philosopher, named Ritter, made *secondary* batteries on this principle, probably without being aware of it, as the theory of them was first made known by Sir Humphry Davy. Ritter formed a pile of alternate plates of one kind of metal, and paper moistened with water, or with a solution of some salt. When this pile had been subjected to the action of a powerful Voltaic battery for some time, and afterwards removed from the circuit, it was found to possess all the properties of the original battery, as though it had been constructed of two metals. This pile is frequently alluded to by writers on Galvanism, and is called the *secondary pile* of Ritter.

Keeping in view the relative electrical states of the *delivering* and the *receiving* bodies, we may bring forward two other parallel experiments, one of which is by the machine, and the other by the Voltaic battery. If we immérse two small brass balls, or even blunt-ended wires, in a tumbler of water, and connect one with the *prime*, and the other with the *negative*, conductor of the machine when in action, sparks are seen passing from the *delivering* to the *receiving* ball, as decidedly as in the open air; and therefore these balls are, relatively, *positive* and *negative*, as definitely in one case as in the other.

We next connect these two wires with the two poles of a powerful Voltaic battery, and after having brought the two terminals together beneath the surface of the water, we gently withdraw the one from the other, and we have a beautiful play of the electric fluid between the two. If, instead of using metallic terminals in the water, those wires terminated with charcoal, the display of fire would be still more splendid. Now, since no electric discharge can possibly take place independently of a *pre-polarization**, these experiments demonstrate an electro-polarity of the metallic and charcoal terminals, although surrounded by water.

Having thus shown the means of recognizing the polarizations of those bodies which are placed in a Galvanic circuit *exterior* to the battery, we will now offer an experimental illustration of those polarizations which take place within the body of the apparatus. If we had no other facts to offer than those attendant on the experiments of Fabroni, they alone would be sufficient to prove the existence of an electro-polarity within the battery, when the circuit is closed. The following, however, being of a more striking character, may be introduced with advantage in this place.

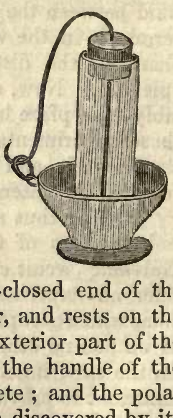
If we employ the bladder-partitioned vessel, described in page 151, and a Voltaic pair of platinum

* Lecture vii, on Electricity, page 99.

and zinc wires, and place in the platinum compartment, a solution of sulphate of copper, and in the zinc compartment, a feeble solution of sulphuric acid, the platinum immediately becomes cased with copper, which indicates its electric condition, relatively to the liquid in which it is placed. If in the platinum cell, a solution of gold be placed, the wire soon becomes gilt by the gold which is liberated from the solution. By a similar arrangement, with a solution of nitrate of silver, and either a gold or a copper wire, the silver would be liberated, and by attachment to these wires, would encase every part of them which was immersed in the liquid.

When a solution of the acetate of lead is operated on, the result of the experiment is very beautiful, by employing an apparatus such as that represented by fig. 83. It consists of a glass tube, one end of which is closed by a piece of bladder ; a zinc basin, and a copper wire. In the zinc basin is placed a weak solution of either the sulphuric or the muriatic acid, and the glass tube is to be nearly filled with a clear solution of acetate of lead. The copper wire being passed through a cork that fits the bore of the tube, one end of it is placed in the acetate solution, and the bladder-closed end of the tube is immersed in the acid liquor, and rests on the bottom of the basin. When the exterior part of the wire is brought into contact with the handle of the basin, the Galvanic circle is complete ; and the polar character of the copper wire is soon discovered by its receiving the particles of lead which are liberated from the solution. The recovered lead shoots into beautiful spangles, or shining leaves, which grow to a considerable size. When a straight vertical wire is employed, like that represented in the figure, the lead tree is liable to slip off; but if the wire be

Fig. 83.



twisted into a spiral form, this accident is prevented, and the tree will sometimes grow to the full dimensions of the tube.

Now, in all these cases the polarized metals were within the battery, of which they formed their respective portions. It will now be interesting for you to know, that portions of metal placed within a battery of which they *do not* form a part, will also become electro-polar. We will first employ a pair of copper and zinc, and unite them by wire, in the manner shown by fig. 53, page 127. We immerse this pair in a solution of sulphate of copper, and between these metals we place two or three short pieces of platinum wire, arranged in the manner shown by the darts. In one moment every wire becomes tipped with copper at those ends which are presented to the zinc. The copper accumulates in time, but none ever appears at the other extremities. By reversing the wires, the copper first deposited soon quits them, and a similar deposition takes place at the other extremities. If instead of placing the wires above one another, they are laid side by side at the bottom of the vessel, or even placed in one row, their polarization is still as complete, and the copper will invariably attach itself to their negative or *receiving* poles.

When zinc is immersed in cuperous solutions, it liberates a considerable quantity of the copper, which by attachment, soon slackens the power of the principal current; but for short illustrative experiments of this kind, that circumstance does not interfere, nor does it injure the battery for future experiments. Therefore, we will now employ a Cruickshank's, of fifty pairs, the cells of which shall be charged with a solution of sulphate of copper. We now take ten short pieces of platinum wire, each of which is stuck in a strip of card, which holds it by the middle. The upper ends of the cards are fixed to a light wooden beam, at proper distances from one another, to allow of the wires being

immersed in any ten successive cells of the battery; with their axis in the direction of the battery's length. When the battery is charged, and its poles united by a wire, we dip the ten wires into ten neighbouring portions of the cupreous solution. When we lift them out again, we have ten copper and ten platinum extremities; each wire having become electro-polar whilst in the battery. We reverse the wires in the battery, and in a few seconds the former copper ends have become platinum ends; and those which before exhibited a platinum surface, are now covered with copper. From these facts, and many others that might be made, we are led to understand, that *within* the battery, as decidedly as *without* its poles, there exist electric currents. That the metals are polar, and that besides their important functions as the primary elements in the battery, they have others imposed upon them, and take an active part in *conduction* as well as in the *excitation* of the electrical element.

Notwithstanding the importance which necessarily attaches to the polarization of the elements of the battery, there is yet another theoretical point to be considered before we can have a proper idea respecting the continuance of the current. In the first place, then, there are no *continuous* electric currents known independently of *motion* in some of the generating elements. Electric currents from the common machine, depend upon the motion of the glass. Those from a thermo-electric apparatus depend upon *motion* of the calorific matter; and those generated in magnetic electricity, are continuous only whilst the magnet or magnetized body is in motion. Indeed, it is a law, which might be mathematically demonstrated, that no continuous electric current can possibly exist in any piece of apparatus, independently of a pre-existing motion in some other element employed. Therefore, the continuous currents which flow through a Galvanic circuit, must, of necessity, depend upon the *motion* of some of the elements

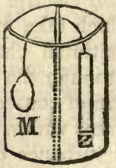
within the battery; and that such motions do exist amongst the elementary constituents of the liquids employed, we have ample proof. Previous to closing the circuit by introducing the twelfth pair of metals, in the *courrone des tasses*, fig. 73, page 161, an electric equilibrium prevails, and no commotion can be detected in any of the glass vessels. But the moment that the polar union is completed, the concentrated electric forces burst from their imprisonment, tear asunder the elements of the liquified compounds, and distribute them, with the rapidity of lightning, to new positions in the circuit, according to their electric relations with those elements of the battery which are either absolutely *fixed* in those positions, or otherwise constrained to remain there. Hence it is, that decomposition is the first act performed by the electric forces; and the distribution of the elements thus separated, gives a new distribution to the electric fluid, from moment to moment, as rapidly as it can be polarized at the fixed elements of the battery. The *secondary* actions which are incessantly going on, and forming new compounds, in a closed circle, also assist in disturbing the electric fluid; and when one of the metals is unamalgamated zinc, the *local* electric actions, both *primary* and *secondary*, which take place on its surface, tend to keep up a continual change in its electric character. Hence, although the original force is the electrical, a succession of consequential events, amongst the elementary atoms within the battery, are essential to a continuous disturbance of the electric fluid, as decidedly as a *pulsatory* current, in the dry pile, depends upon the pendulous movements between its poles, which are events consequent upon the pre-existence of electric forces.

Electro-typing, Electro-silvering, and Electro-gilding.—The theory upon which these arts are founded, has already been illustrated by the experiments on metallic solutions; and one of the grand points to be kept in view, is to keep the battery

power within such limits as to decompose nothing more than the metallic salts in solution; because, should any part of that power be exerted on the water, so as to accomplish its decomposition, the liberated hydrogen gas would interfere with the metallic deposition on the *receiving* terminal metal, which, in all these processes, is that which is intended to be covered.

When any article is to be electro-typed, for the purpose of obtaining *fac similies* of an original production, a medallion for instance, the surest way of arriving at the wished-for result, is to employ the medallion itself. Let us suppose that it is of copper. Then the vessel divided into two compartments by a bladder partition, already described, (page 151,) would answer well for holding the liquids to be employed. The medallion is to be furnished with a thin copper wire, which passes round its edge, and there made fast by a twist. The other end of the wire is to be furnished with a piece of zinc; and this Voltaic pair is then to be placed in the two chambers of the box, in the manner represented by fig. 84, in which M is the medallion and Z the zinc, with their faces parallel to each other. The cell in which the medallion is placed is filled with a strong solution of the sulphate of copper, and the other cell is filled with water. A Galvanic action commences, and in a very short time that face of the medallion next to the zinc, becomes covered with copper which has been liberated from the solution, and the coating thickens with the time allowed, until the whole is extracted from the liquid. If, however, the liquid be fed by fresh portions of the sulphate, the process will go on as long as you please, and the thickness of the copper deposited on the medallion will be proportional to the quantity of the salt decomposed. The zinc must either be of sufficient thickness to

Fig. 84.



last all the time, or new pieces must succeed each other during the process.

The metal thus deposited is in a firm compact mass, and may easily be peeled from the medallion, of which it has taken an exact impression, and with a face of equal polish, and, generally, much more brilliant. As, however, the off surface of the medallion, when left bare, receives a thin layer of copper, it is well to cover it with lac varnish prior to the Galvanic operation. This first electro-type is now to be employed in precisely the same manner as the original medallion was employed in the first process; and the electro-type formed in this matrix will be a *fac simile* of one side of the medallion. And, with care, a great number may be formed in the same matrix. To obtain *fac similies* of the other face of the medallion, a similar process must be pursued. A matrix for each side of the medallion may be formed at one and the same time, by employing a vessel with *three* compartments; in the centre one of which the medallion is suspended in the cupreous liquor, and in each of the others, a piece of zinc with water. The edge of the medallion, with its surrounding wire, are to be covered well with varnish, which will prevent metallic deposition on them. By similar processes, *fac similies* of brass, silver, gold, and platinum medallions, or coins, may be obtained. But when the metal of the original is lead, tin, zinc, &c., a battery must be employed, otherwise the acid liquor would deface them.

When the article to be electro-typed is large, such as a copper-plate from which prints are taken, it may be laid horizontally, with its face upwards, at the bottom of a water-tight box, and covered with a solution of the sulphate of copper. Over this is to be placed a diaphragm of bladder, parchment, or strong paper, stretched on a wooden frame, and supported an inch, or more, above the copper plate. The diaphragm with its frame, forms a tray, in which water and a sheet of zinc is placed; and when the

two metals are united by wire, the Galvanic circle is complete, and the upper surface of the copper plate receives the liberated copper from the solution. When the action has proceeded about twelve hours, both portions of liquid should be removed and new ones introduced to their places. By paying attention to the renewal of the liquids and the zinc plate, the electro-type will be sufficiently thick, from about two days' action, to be peeled off the original. By a similar process, many *fac similies* of the original may be obtained, by operating with this first electro-type production. From these *secondary* electro-types, prints may be obtained as decidedly as from the original plate, and exhibiting all the minutiæ of the picture with the same degree of precision.

When an original article cannot be obtained for an electro-type operation, a mould may be formed on it, in which an electro-type may be deposited. The best moulds are metallic, and the simplest way of procuring them for coins, or small medals, is to squeeze the original between two pieces of clean sheet lead, in a strong vice, or by some other means. The lead yields to the pressure, and takes a tolerable fair impression from the two faces of the original.

Another method of obtaining metallic moulds is to employ the fusible metal, which consists of bismuth, lead, and tin, in the proportions of two of bismuth and one of each of the other metals. This alloy fuses below the temperature of boiling water, and may be kept in a pasty condition whilst worked in the hands. When in this soft state, the article to be electro-typed is to be pressed upon it, with all the precautions necessary to exclude every particle of air. When the alloy has become solid by cooling, it is to be removed from the other metal, and used as a matrix in the electro-type process. These moulds are to be attached to the *negative* pole of a battery of two, three, or more elements in series, and immersed in a solution of sulphate of copper. To the *positive* pole of the battery is to be attached a plate of copper,

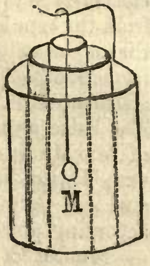
which is also to be immersed in the cupreous solution. The decomposition commences, and copper is deposited in the mould, and at the same time the copper plate oxidizes, and dissolves in the liquid, by which means a supply is kept up. When the metal of the electro-type is sufficiently thick, it is to be removed from the mould, and the latter being re-immersed in the solution, another electro-type commences its formation. The copper plate terminal must be attended to, in order to keep up the necessary supply. The battery may be either of Daniell's form, or that of Mr. Mullins; or it may be the cast iron battery, with a very weak solution of sulphuric acid. The size of the Galvanic metals must be regulated according to the work to be performed.

Moulds of bees' wax are sometimes employed, but they are never so good as those made of metal. The wax moulds are lined with a fine layer of black-lead, laid on with a soft brush.

The process of *electro-silvering* is somewhat different to that of electro-typing. The principal point to be observed, is to procure the most suitable solution of silver to work upon, or such a solution as may easily be decomposed, and from which a fine and firm coating of silver may be obtained. There are several solutions of this kind in common use. The cyanuret of silver,—the ferrocyanuret of silver,—the hyposulphite of silver, &c. The articles to be silvered are to be well cleaned from grease, dirt, and all foreign matter; and it is well to dip them into a very weak solution of nitric acid, the moment before they are to be submitted to the battery action. The simplest battery that can be used, is that of which the article to be silvered forms a part, similar to that described for the electro-typing process, and represented by fig. 84. In one of the cells is placed the silver solution, and in the other a weak solution of sulphuric acid; and when the article and the zinc are united by wire, they are placed in their respective liquids. In a few minutes, the silvering of that side of the

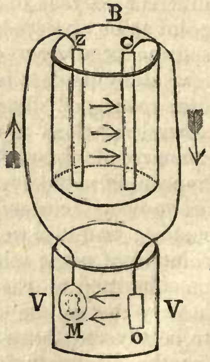
article* next to the zinc will be complete; and probably a slight coating may appear on the other surface. But when the article is to be silvered on every side, the apparatus represented by fig. 85, will be found convenient. It consists of a porcelain jar, within which is placed another jar; but this latter is porous,† and contains the solution of silver. The space between the two jars holds a hollow cylinder of zinc, which surrounds the porous jar, and a weak solution of sulphuric acid. A wire rises from the zinc, and bent at right angles for the purpose of supporting and keeping contact with the article in the silver solution.

Fig. 85.



When a separate battery is used for the silvering process, the solution of silver is placed in a vessel called a *decomposing cell*, which may be a wine glass, a jar, or any other convenient article. In fig. 86, V V represents the decomposing cell; and the jar B, containing a copper and a zinc plate C, and Z, is a separate battery of a single pair. The zinc is connected with the article M, to be silvered; and the copper is connected with a silver plate O, which will dissolve as the process goes on, and keep up a charge of silver in the liquid. The arrows and darts indicate the course of the electric current.

Fig. 86.



Gilding is carried on in precisely the same manner, and the auriferous liquids are similar to

* The article may be a copper coin for a first trial.

† Apparatus for this purpose may be had of the Philosophical Instrument Makers.

those in which the silver is dissolved. Some times a battery of four or five elements in series is employed in both processes. This hastens the work, which is sometimes accomplished in a few minutes. It is never necessary to have a Galvanic series of more than four or five pairs; and the size of the plates must be regulated by the magnitude of the article which is to receive the silver or the golden covering. The mode of connecting the article with the battery, may be any that is found most convenient.

It is a remarkable fact, and one of great importance in the above arts, that, although some metallic moulds and other articles will dissolve, in the liquids employed, when not connected with the battery, they are completely protected when united with the *negative* pole, and become the *receiving* terminal. If, for instance, we place two copper wires in a weak solution of nitric acid, such as would slowly dissolve the metal of both. When the dissolution has proceeded for a few seconds, and we connect the wires with the poles of the battery, the action is immediately arrested on the *receiving* terminal wire, but increased on the other. From this fact we learn, that the article to be electrotyped, silvered, or gilt, ought to be the last body that is introduced to the Galvanic circuit, in order that its surface may not be injured by local action.

Mr. De la Rue, the ingenious manufacturer of such a variety of fancy and other articles, seems to be the first person who observed electro-type impressions of great accuracy, in some of his Galvanic apparatus; but we are indebted to Professor Jacobi, and Mr. Spencer, for its first appearance as an art.

Advantage is taken of the gilding process in the art of etching copper plates. The surface intended to receive the etching, is first covered with a thin coat of gold, through which the tool can make the finest lines imaginable, without danger of breaking

the gold covering. The biting liquor having no power on the gold, acts in the lines only. A similar application of copper has been made, by covering steel plates with it, and tracing through the copper.

An attempt has lately been made to take advantage of the secondary actions as a source of printing on calico and other fabrics, a specimen of which may be interesting in this place. An iron block, with any device, in relief, on one of its surfaces, is procured. The article, calico, for example, is well soaked in a solution of ferrocyanuret of potassium, and afterwards dipped in a solution of nitrate of soda. When the redundant liquid is squeezed out, the calico is spread smoothly on a sheet of tin foil, which is to be connected with the negative pole of a battery, and the iron pattern is placed upon the calico, and connected with the positive pole. By this means, the surface of the pattern becomes oxidized, and the oxide combining with the ferrocyanuret in solution, forms prussian blue, and a very exact blue impression of the design is left on the calico. Other metals produce other colours, and by having various metals in the pattern, a variety of colours may be printed at the same time. The iron battery of about ten jars, fig. 59, page 137, will print remarkably quick. With twelve or fourteen pairs in series, the impressions might be made almost as speedily as the pattern could be adjusted to its proper place on the fabric. The idea of electro-printing, seems to have originated with Mr. Baggs, of London.

By a similar process to that above, writing ink may be easily formed. For this purpose we employ a solution of common salt, and mix with it an infusion of galls. A portion of this liquor is placed in each of two wine glasses, and connected by tow, or loose spun cotton, well soaked in salt and water. The terminals are to be iron wire. The positive terminal is soon oxidized, and a black liquor, (ink) is produced, but no such colouring is observed in the other vessel. Fifty pairs of metals in series,

answer very well for this experiment. If we want a blue ink, we have only to employ a solution of the ferrocyanuret of potassium, in place of the infusion of galls.

LECTURE XII.

ALTHOUGH we have given several cases of the electro-polarization of bodies, when surrounded by liquid conductors, there are still some others to be noticed which may probably give a pretty accurate idea of the mode by which the Torpedo, and Electrical Eel, arrest their prey before delivering the fatal shock. When small fish are placed in a basin of water, the two opposite sides of which are connected with the poles of a Galvanic battery, the current, which spreads through every part of the water, soon disturbs them, whatever part of the water they may be swimming in, and very frequently draws them into a line with the terminal wires, gradually exhausting their strength until they become quite lifeless. When several frogs are in the water, they very soon become arranged in the axis of the current, one behind another, and there remain quite motionless, though not dead, until the current is discontinued. Some of the frogs will take hold of one of the wires with its fore feet, and there hang in the water during the whole time. But when the current is powerful, they become stunned, and unable to swim for a long time after the process has ended. A volley of discharges, by running one of the conducting wires over the edges of the plates, has the best effect.

It appears to me that these animals, when in the axis of the current, cannot avoid being electro-polar, for they are in the best possible position for being forced into that state; and I have no means of understanding why they are drawn into that position, unless by a similar action on them whilst at some

distance from the *axial-plane.** Admitting this to be the case, it is not difficult to suppose that the battery of the electric Eel would polarize fish at some distance from it, and would thus draw them closer, until they were in a proper position to receive the fatal blow.

Leeches and snails are very much disturbed by touching zinc and another metal in contact with it, at the same time. Neither of them will travel across the joining of these two metals. Advantage has been taken of this fact, to keep snails from young garden plants, by placing a Galvanic fence of copper and zinc, round the beds in which they are growing.

It is very likely that animals suffer much from a decomposition of their fluids during Galvanization. This chemical action is shown in a very decisive manner, at those points of the skin of a dead animal, which the polar wires touch, and putrefaction soon follows. There seems to be in Galvanism, an agent of immense value to the epicure, by means of which he might obtain venison much earlier than by the usual natural process.

The porter drinker, also, derives his favourite flavour from the Galvanic action occasioned by the saliva, the porter, and the metallic pot, which form a Galvanic group. A zinc pot renders the porter too sour to be agreeable.

There are many facts which induce us to believe, that there is not an uniformity of electric tension amongst the particles of any one piece of metal, and that it is on this account that they individually act on acid and other liquids *Voltaically*, and thus accomplish their own dissolution. In illustration of this view, I will offer an experiment.

We nearly fill a glass tumbler with an exceedingly weak solution of sulphuric acid, and place at the bottom of the vessel, a piece of clean rolled zinc.

* As the wires usually reach to the bottom of the water, the greatest force of the current must be in a vertical plane between them. This is what I mean by the term *axial-plane*.

Hydrogen gas is seen rising from a very few points on the surface of the zinc, and at some distance from one another. These points from which the gas rises, may be considered as so many *negative* Voltaic poles. I now press the lower end of a thin copper wire near to one of these gaseous fountains, and immediately it either disappears, or its activity is much abated. Should the latter be the result, I bring the wire still nearer, until the fountain is perfectly annihilated; and by applying a wire to each fountain, on the surface of the zinc, I close the whole of them. Gas rises in abundance from every copper wire, but not any from the zinc. Now, the wires and the zinc form *artificial* Galvanic combinations, whose energies have overpowered those of the zinc. But when the wires are removed the zinc resumes its Galvanic functions, and again becomes capable of decomposing the water.

This view of the action will afford a tolerable good idea why metals, whose surfaces were quite smooth prior to their immersion in an acid liquor, should become rough, or asperous, during their dissolution in it; and we may select zinc as an example. I have already shown that the *negative* polar metal is preserved at the expense of the *positive* one; and we have many experiments which show that, when *one* of two pieces of the same metal is oxidized and the other clean, the Galvanic relation of the former to the latter, is the same as copper to zinc in the standard battery.

With these facts before us, we will proceed to reason on the process of dissolution of zinc in a sulphuric acid solution. The relative *positive* and *negative* poles on the metallic surface commence their Voltaic decomposing functions; the former combine with oxygen, and the latter liberate hydrogen, and they are, respectively, *destroyed* and *protected;* and the latter points are consequently left prominent, and the general surface rough. In a short time their Galvanic relations change, both on

account of one being kept clean and the other dirty; and because the acid meets with new metallic particles in the late *positive* cavities. This electric change reverses the points of *attack* and *protection*, and the prominent places would now be reduced. But as these reverses of action from point to point are continually going on, at different times in different places, and with the greatest irregularity imaginable, the surface of the wasting metal is kept continually rough, from the first moment of its immersion till its final disappearance.

This theoretical view of the action of simple metals on the particles of those liquids in which they dissolve, affords an explanation upon well-established principles, and will account for every case. I published it in my pamphlet, in 1830, but I am not aware that it has elicited much attention from chemical philosophers, although they have no means of explaining the phenomena that are produced during the dissolution of metals, upon any other principles.

There are some very beautiful productions by the Galvanic action of certain metals, upon other metals whilst in solution. If, for example, we place in a glass bottle, a solution of the acetate of lead, and suspend a piece of zinc in the solution, the Galvanic forces of the zinc immediately set to work on the acetate, and accomplish its decomposition; the oxygen uniting with the *positive* polar points, and metallic lead attaching to the *negative* polar points. When the surface of the zinc has thus become partially studded with metallic lead, a regular Voltaic battery is formed by the lead and the zinc. The action now becomes rapid, and shining leaves of lead shoot forth on every side; and in the course of about two days, the bottle will be nearly

Fig. 87.

filled with the pendant *philosophical tree.* This interesting production has the best effect when grown in a decanter, the body of which is of a globular form. Fig. 87 will give some idea of its appearance.

It is somewhat remarkable that Fabroni, who made a great number of experiments on simple Galvanic pairs of metal, by which he invariably increased the oxidation of one of each pair, took no notice of the reverse property, or the protection, of the other metal. Sir Humphry Davy took the first advantage of this fact, in the protection of the copper of ship's bottoms from the action of sea water, by attaching a piece of zinc to it.

Unfortunately, however, this direct application of well-founded philosophical principles, was prevented from returning the expected advantages, in consequence of its neutralizing those poisonous qualities of the copper which deterred a species of marine animals from lodging and colonizing upon it. For now that it became inert, by Galvanic protection, against the attacks of sea water, these barnicles assembled upon it in multitudes, forming immense groups, which retarded the vessel's speed whilst sailing; and by thus counterbalancing the skill of the philosopher, this beautiful application of the Galvanic theory became null, and was soon obliged to be abandoned.

The most brilliant of Davy's discoveries, consisted in his decomposition of potash and soda, in the year 1808; and his masterly train of reasoning on the results, and a succession of successful experiments consequent thereon, placed chemistry in the most intimate connection with electricity, and marked a new era in the science. The alkalis operated on were in the state of hydrates; and the battery employed by Sir Humphry consisted of 250 pairs, the plates being six inches by four, and in an intense state of action. A piece of potash was laid on an insulated disc of platinum, which was the *negative terminal* of the battery; and to the upper

surface of the salt, a platinum wire was brought from the positive pole. The potash melted with an effervescence at the *positive* terminal, and the metal, potassium, was liberated at the negative, in strict accordance with the law observed in the decomposition of other metallic salts. The potassium was obtained in small shining globules, many of which were ignited, and burst into flame or scintillations, and disappeared. Sodium was liberated from soda by a similar process.

These metals are never obtained in large quantities by the Galvanic process, but small portions are easily obtained by a battery of thirty pairs of plates; and it is always advisable to use no more power than is just sufficient to decompose the salt, to prevent deflagration of the liberated metal.

Potassium is easily obtained amalgamated with zinc, by the power of a battery of ten or twelve pairs. The mercury is placed in a saucer, or any convenient vessel, and connected with the negative pole. The salt is laid on the mercury, and the positive terminal brought into contact with its upper side. This terminal may be platinum, gold, charcoal, &c. Mr. Thos. Mason,of High Holburn, employs charcoal for the positive terminal; and has obtained considerable quantities of the metal by a battery consisting of twelve pairs, in small jars, upon the principle of Mr. Daniell's battery.

The amalgamation of potassium by this means is a tedious process, unless large quantities be operated on at a time. There are some singular phenomena exhibited by the potash and mercury, which may be worthy of notice. When a platinum point from the positive pole just touches the upper side of the potash, a small hole is immediately formed in the latter, which becomes a pivot-hole for the metallic point, and a rapid rotation of the salt commences round this axial pivot; and this motion may be kept up for a quarter of an hour or longer, by keeping a nice adjustment of the point to the hole.

At the same time the mercury seems to be in a state of continual commotion. If the piece of potash be angular, as is generally the case, it may be made to exhibit a continuous pulsatory or vibratory movement, by a nice adjustment of the platinum point to one side of a projecting angle. There are other phenomena which the experimenter meets with, but which are not easily described.

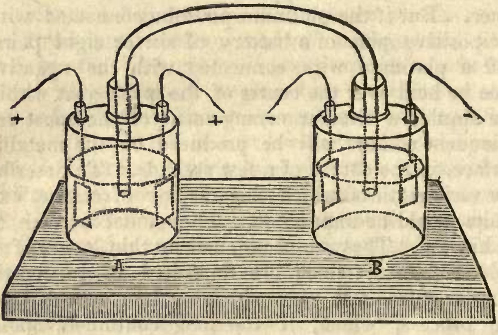
One of the most beautiful classes of electro-chemical phenomena is the *Chromatic*. It was discovered by the late M. Leopold Nobili, of Reggio, in the year 1826, and by that philosopher called *Metallo Chromy*. When a plate of platinum is laid in a dish and covered with a thin stratum of a solution of acetate of lead, there appears to be no action taking place. But if the platinum plate be connected with the positive pole of a battery of six or eight pairs, and a platinum wire connected with the negative pole be held over the centre of the plate just within the liquid, a circular arrangement of the most resplendent colours will be produced on the metallic surface, in the course of a few seconds. To describe the various tints which this display of colours exhibits would be impossible. They must be seen to be known. They are occasioned by thin layers of an oxide of lead, which are deposited in concentric annular piles, and vary with the time occupied by the process, which, if too long continued, spoils the whole. Highly polished steel displays these colours still more beautifully than platinum. When devices are cut in cardboard, and placed over the surface of the steel plate, those portions of the card which adhere to the plate prevent the deposition, and the colours are produced in the open spaces only; and in order to communicate the action to the whole of these, that is, to the whole device, at once, an inverted hollow copper dish rests on the margin of the card, its upper surface, (which is immersed in the liquid,) being connected with the negative pole. This contrivance, I

believe, is due to Mr. J. Gassiott, of Chapham Common.*

With Galvanic powers of low tension, when long kept in action, many of the productions of nature may be very strikingly imitated; and from the success which has attended the labours of Professor Becquerel, of Paris, and Mr. Robert Were Fox, of Falmouth, the door has been opened to the inmost recesses of nature's operations in the mineral kingdom. The following experiments will afford a good idea of the nature and importance of M. Becquerel's enquiries.

One of the pieces of apparatus is represented by fig. 88. It consists of two small glass vessels,

Fig. 88.



a bent glass tube, and two plates of platinum. In one of the jars is placed nitric acid, and in the other a solution of potash. They are connected with each other by means of the bent glass tube, filled with potter's clay, well saturated with solution of nitrate of potash, or chloride of sodium; and the two platinum plates are connected by the wires + and −. When the jars are kept closed, this apparatus forms a permanent battery of one pair;

* The apparatus which I employ for this beautiful experiment, was obtained from Messrs. Watkins and Hill, Charing Cross.

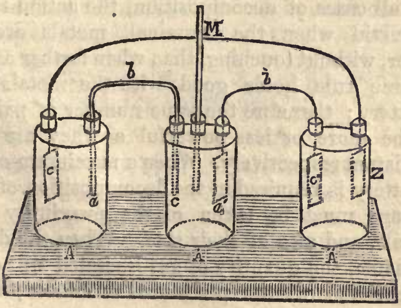
and by carrying on the communication to other similar arrangements, by means of other platinum plates and wires, in the manner represented by the outermost in the figure, a series to any required extent may be formed. By means of these apparatus, Becquerel is enabled to carry on the action of a feeble power for a long time; and the products are various, according to the metals and salts employed. Those described being merely to show the arrangement in these enquiries.

Fig. 89.

Another apparatus is represented by fig. 89. It consists of a glass tube, within which is a plate of copper. The tube is closed at one end, and in the lower part is placed some deutoxide of copper. The copper plate is then inserted, and rests amongst the deutoxide; and the tube, after being filled up with a saturated solution of nitrate of copper, is hermetically sealed. It is kept in a vertical position, by the wooden block. In about ten days from the commencement, bright crystals of copper, of an octahedron form, are seen on the copper plate. Various other compounds are formed by varying the proportions of the nitrate and deutoxide.

Another piece of apparatus used by Becquerel,

Fig. 90.



is represented by fig. 90, in which A A' A" are three glass vessels. In the first is placed a solution of nitrate, or sulphate of copper; in the second, a solution of that substance on which the changes are to be produced; and in the third, some acid or saline liquid which will act chemically on the metals which are to be placed in it. A communicates with A', by means of a bent tube *a b c*, filled with clay, moistened with such a saline solution as is intended to produce a certain effect in the vessel A. A' and A" are joined by wire and two platinum plates *a' b' c'*, and A and A" are united by a Voltaic pair of copper and zinc, C and Z, and the wire M. A safety tube *t*, is introduced to the vessel A, to indicate the pressure arising from the liberation of gas.

If in the vessel A be placed a solution of copper, and in A' an alcoholic solution of sulpho-carbonate of potash, and that the clay in the tube *a b c*, be moistened with nitrate of potash, crystals of sulphur, and of neutral carbonate of potash, are formed on the lower edge of the plate *a'*. Other products arise from other sources similarly arranged. Mr. Fox's experiments were, principally, on metallic ores, transforming them from one state to another.

The amalgamation of the surfaces of iron, copper, antimony, &c., is very quickly accomplished by placing the bar and the mercury in contact, and each connected with the pole of a battery.

In all cases of decomposition, the action is much more vivid when the terminal metals are close together, without touching, than when farther asunder. The same rule holds good with the metals within the battery; therefore the same number of pairs may more be more or less powerful as they are less or more distant respectively. When a maximum effect of any battery is required in the decomposition of water, advantage must be taken of the proximity of the terminals, and also of their size. When the distance is the same, the quantity of gas liberated will depend upon the size of the platinum terminals; and as

the size of the terminals requisite to give the full effect will depend upon the size of the battery plates, it would be in vain to look for one individual pair of terminals, that would allow of the maximum effect for all the different kinds of batteries that are in use.

There is also another particular to be attended to in order to obtain maximum effects with various batteries. Each individual compound requires a certain *specific* degree of intensity of the Galvanic force, to just balance the force with which its constituents are held together. And any force greater than that, will accomplish its decomposition. When this latter force is greater than necessary, all the redundant part is lost; and the battery series may soon be extended so far as to reduce the decomposing action much below that which a smaller number of pairs would produce. The only means of arriving at a knowledge of the *series* of any battery, that yields the best results, is from experiment. The following results of a series of experiments on this enquiry were obtained from four different kinds of battery. The terminal patinum plates were large, both of them exposing a surface of 144 square inches.

The series which gave maximum decomposition with

Groves' battery, was	10 pairs.
Cast iron do.	12 do.
Smee's do.	10 or more.
Daniell's do.	5 pairs.

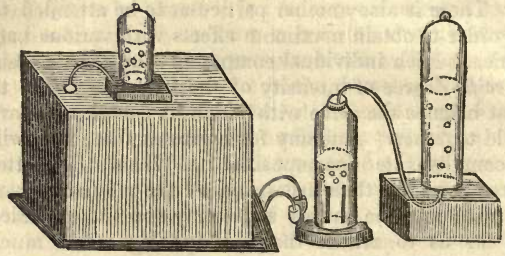
By reducing the size of the metallic pairs to one common standard, the gases collected in one minute would be as below:

Groves'	24	cubic inches.
Cast iron	14.8	do.
Smee's	8.1	do.
Daniell's	5.5	do.

With the cast-iron battery, a considerable quantity

of gas is liberated from the acid liquor; but by employing a japanned cover over the jars, in the manner represented by fig. 91, the nuisance is prevented. The apparatus on the top is for the purpose

Fig. 91.



of collecting the escaping gas: but it is now dispensed with, as the cover is large enough to hold all that escapes from the battery, for any moderate length of time. There are two stout copper wires which proceed from the two poles of the battery to the two cups holding mercury; and these cups are in connexion with the platinum terminals within a glass vessel, which constitutes the *decomposing vessel.* The liberated gas passes to the pnuematic trough through the bent pipe, and is collected in a graduated receiver, which is the *electro-gasometer.* The bottom of the decomposing cell is of wood, and being fixed to the glass by cement, it frequently gets loose, and the instrument becomes leaky.

I now use another kind of decomposing cell, which consists of a large glass jar, with a welt round its mouth, and three necks near its upper end. The margin of the open end is ground, to be air-tight with a disc of plate glass, with which it is covered, and kept down by a weight. Within the jars are two parallel platinum plates, each six inches square; to the top of each plate is soldered a brass wire, which is bent at right angles, and passes through a cork

in one of the necks. The central neck, or that which is formed between the other two, receives one end of the bent glass tube, by means of which the gas is conveyed to the *gasometer*. Fig 92, is a vertical section, with the edges of the *terminal plates* towards the eye; and fig. 93 is a section with the eye towards the face of the plates; in which view it shows the tube also. By this contrivance, the terminal plates can be adjusted to any required distance from one another; and the whole being glass and metal, the vessel cannot leak.

Fig. 92.

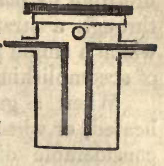
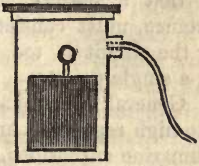


Fig. 93.



The only remaining class of electro-chemical phenomena that I have to notice is the calorific. And here it is that the grand field opens for the display of that superiority of action which one kind of battery has over another; and in this field also, it is, where *quantity* and *intensity* of the electric fluid, have the fairest opportunity of displaying their respective agencies whilst operating on various kinds of matter. The miniature battery of Wollaston, made of a lady's thimble and a morsel of zinc within it, will ignite a piece of thin platinum wire: but if the thimble were large enough to encompass an acre of zinc surface, its powers would never accomplish the deflagrations of charcoal and thin laminated metals. Nevertheless, fifty pairs, in *series*, of the size of a lady's thimble, would display the latter phenomena.

This contrast between the effects of *quantity* and *intensity* ought always to be borne in mind by the experimenter who wishes to turn his batteries to account. One single pair of metals of a square foot each, will heat a *thicker* wire than the same quantity of metal will heat it, if made into a battery series of *one-inch* plates; but in the latter form it will

deflagrate metals with a crackling noise, and project its fire from its *positive* to its *negative* charcoal terminals, through a stratum of intervening air; phenomena, which a single pair, however large, has not the power of accomplishing.

When a great *length* of wire is required to be heated, or when a small piece is to be heated, at a considerable distance from the battery, a greater *intensity* is requisite than that of a single pair. In both cases there wants a projecting force. Thus it is, that a battery for exploding gunpowder at a distance, must consist of a *series* of Galvanic pairs, for the circuit is too long to accomplish the object by a single pair.

General Pasley has brought the Galvanic battery into high repute, as an engineering implement, by his submarine explosions, which have been attended by such brilliant results. The removal of the wreck of the Royal George from the best anchorage at Spithead, and the instantaneous overthrow of the immense masses of matter from the proud cliffs of Dover, are scientific exploits that will ever be associated with the name of this distinguished officer.

The method of exploding gunpowder by Galvanic action, is simply that of heating, to redness, a thin wire of platinum, which passes through the powder. There requires, however, a peculiarity of adaptation of the arrangement, to the circumstances attending the undertaking. To explode gunpowder in the open air, nothing more is required than two copper conducting wires, each of which would reach from the battery to the site of the explosion, and about an inch of thin platinum wire to join their extremities at the latter station. The platinum wire must pass through the powder; and in order that the explosion may take place at any required moment, one of the conductors must be attached to its battery pole. The other conductor being held in the hand is ready to complete the circuit, whenever the word "fire" is given: and the moment the conductor touches its proper pole, the explosion takes place.

For the "blasting of rocks," the priming powder is made into a cartridge, having the platinum wire within. In this case, the platinum joins the inner ends of two copper wires, each of which projects a few inches outward, and are tied, by binding wire, to the long conductors. This is also the case in submarine explosions. The cartridge case is a small cylinder of wood, the powder of which, when exploded, ignites the whole charge. The conductors employed by General Pasley, were upwards of 500 feet each, making the circuit more than 1000 feet. They were of copper wire of about one-fifth of an inch diameter. A rope, or bundle, of thinner wires, laid together, would probably answer as well. Each conductor is well covered with tape saturated with a mixture of pitch and tallow, to ensure insulation from each other, and from the sea water. They are wound on a large wooden drum, which is placed in the same boat with the battery, and let off as required whilst the charge is sinking to its destination, to which place it is guided by the men who, in a diving bell, accompany it. The battery consists of a series of twenty* large cylinders of Daniell's form. I believe the General has employed other batteries, but I am not aware which kind he prefers.

The most formidable battery, for igniting metallic wires, that has hitherto appeared, was one made by Mr. Children. It was of the form represented by fig. 28, page 65, and consisted of 20 pairs of copper and zinc, each plate of which was six feet by two feet eight inches. This battery would ignite six feet of thick platinum wire, and fuse iridium and osmium, both of which are exceedingly refractory metals. Mr. Children afterwards increased the power of his battery, by employing double coppers, as in the fashion of Wollaston's.

If we attach to the extremity of each conductor, a piece of the charcoal of boxwood, and bring the

* I believe that I am correct in this number, but the series required will depend on the length of the circuit.

points together, an immediate ignition of the charcoal takes place, and the burning points may now be drawn from one another a short distance, and a splendid play of flame is kept up between them. For this purpose we employ the universal discharger,* and attach to each branch a pencil of the charcoal, in the manner represented by fig. 94. With the extensive battery at the Royal Institution, consisting of

Fig. 94.

2,000 pairs of four-inch plates, Sir Humphry Davy caused the flame to play through four inches of the heated air; and when the charcoal points were surrounded by very attenuated air in the receiver of an air-pump, as represented by fig 95. The space occupied by the flame was much longer. We find, however, that although the charcoal points may be drawn further asunder in attenuated air, the intensity of the light is not so great. With this immense battery Davy fused quartz, sapphire, magnesia, and lime; and small pieces of plumbago, charcoal, and even the diamond were converted into fumes, and entirely disappeared.

Fig. 95.

Dr. Hare states, that the light produced from charcoal, attached to his deflagrator of 300 pairs, had the appearance of sunshine on some adjacent buildings on which it fell.

* This instrument is described in my ninth lecture o Electricity, page 124.

Fig. 96 represents one of the apparatus employed by Sir Humphry Davy, for experimenting upon gases, either with, or without, charcoal points. The

Fig. 96.

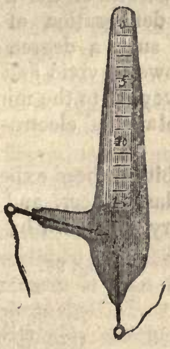
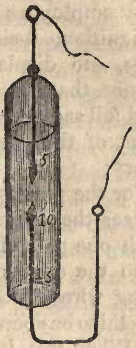


Fig. 97.



side wire is moveable, for the purpose of varying the distance between the points within. Fig 97 represents another form of apparatus, for operating on gases over mercury.

If we employ charcoal points, with twenty pairs of the cast iron battery, the light is but very trifling, but it is much better with the same number of Daniell's large cylinders. The converse of this is the case in the ignition of thick copper wire, which shows that the former battery produces a greater *quantity*, but the latter a greater *intensity*. The same number of Grove's battery is far superior to either of the former, in both capacities. With a series of fifty pairs of Grove's battery, the phenomena are of the most splendid description.

If we employ the pointed charcoal in the manner represented by fig. 94, it scintillates, and is projected in fiery radial sparks, which are thrown to a great distance; and by drawing the points half an inch asunder, a continuous display of intense light is

kept up. The grandest effects, however, are produced between two pieces of coke. The flame between the pieces plays through a thicker stratum of air, and the clouds of ascending smoke increase the magnificence of the spectacle.

By employing mercury as one of the terminals, the ignition, fusion, and deflagration of various metals, are displayed with such a degree of magnificence, that description, however vivid and minute, would fall sadly short of conveying to the mind a true picture of these grand displays of electro-volcanic scenery.

For the purpose of exhibiting these experiments, we place the mercury in a glass saucer, and connect it with one pole of the battery, as shown by fig. 98; and to the other conducting wire we attach the metal to be operated on. When this latter wire N, is of thick copper, we dip it into the mercury; this gives rise to a powerful current. We next withdraw the point, slowly, from the mercurial surface; immediately a blaze of burning mercury commences, and a dense cloud of smoke rises, in the manner represented by the figure. Continuing this action for a short time, the copper wire becomes red hot; fuses, and bursts into large globules, which are projected several yards from the spot; and by thus continuing the experiment, the copper wire fuses and explodes, in succession, as long as we please to continue the experiment.

Fig. 98.

When the terminal N, is twelve inches of watch main-spring, it first assumes a low red heat, which gradually grows to an intense glow throughout its whole length. We now raise its end from the mercury, and a fountain-cascade of fused steel globules starts into existence; and by a nice adjustment of the steel

to the surface of the mercury, the whole twelve inches are reduced to thousands of minute globules; burning the whole time with an intense degree of heat, and forming the most splendid *fountain-cascade* of fire. The burning mercury, also, which sends up volumes of smoke, adds greatly to this grand spectacle. In this manner we fuse steel files of considerable thickness.

When gold or silver leaf hangs from the point N, of one of the conductors, it deflagrates with its peculiar coloured light; and thick tin foil becomes consumed in a moment. We now close the scene of these deflagrations, by an experiment on zinc turnings. We hang a bundle of these turnings upon the end of the conductor N, and bring them down to the surface of the mercury. In one moment the whole bundle is in a splendid blaze, which continues for a short time, and the room is soon filled with floating flocks of *philosophical wool.*

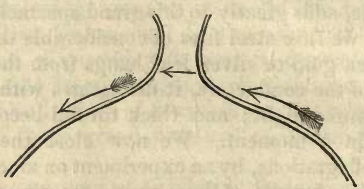
I shall now conclude this long lecture with two experiments, which, to me, appear decisive illustrations of the distinction between the calorific matter and the electric fluid.

If we place in the circuit of a battery, a galvanometer, and, in another part, about a foot of platinum wire, the temperature of which cannot be much elevated by the current, the needle will stand at a certain degree of deflection. We mark this angle, and afterwards heat the middle of the platinum by means of a spirit lamp. The needle retires towards the meridian, in proportion as the wire is heated. If, now, we place two other spirit lamps under the wire, one on each side of the former, the needle retires still farther from its first point of deflection, indicating a still less power in the current. This ascertained, we withdraw all the lamps; the platinum cools, and the needle advances to its first position. This beautiful fact, first shown by Davy, prove that heat obstructs the passage of the electric fluid, and arrests a portion of the current.

We next apply ourselves to an original experiment, in which the calorific matter is driven entirely

out of the channel through which the electric current flows. For this purpose, we employ two stout copper wires, bent into the form represented by fig. 99.

Fig. 99.



These wires, being connected with the two poles of the battery of fifty pairs, of Grove's contrivance, they are brought into contact at the curved parts where the small dart is seen. The heat fuses the surfaces of the wires, and slightly welds them together. We separate them gently, and a flame plays between them; and on withdrawing them a little farther, the current still rushing from one to the other, the *delivering* wire becomes slightly red hot; and on continuing the action, it becomes intensely red, from the part where the current quits it, to its upper extremity; but in no other part is this intense heat indicated. The negative, or *receiving* wire, never assumes a red heat, when the experiment is dexterously performed. The arrows show the direction of the current in the conducting wires, and the dart shows its direction between them.*

* The battery with which this experiment was made at the Royal Victoria Gallery, was purchased of Messrs. Watkins and Hill, Philosophical Instrument Makers, Charing Cross, London. It is now in the hands of Mr. Dancer, Philosophical Instrument Maker, Cross Street, Manchester. The experiment was *originally* made by a battery of 160 pairs of small copper and zinc cylinders, in porcelain jars, part of which belonged to Mr. J. Gassiot, of Chapham Common, and part to Mr. T. Mason, of High Holborn. The zinc was placed within the copper, and insulated from it by brown paper. The liquids were solution of sulphate of copper, to the copper, and salt water to the zinc.

By the former of these experiments we understand, that an additional quantity of the calorific matter *forced* into the electric channel, occupies a portion of that channel, and leaves proportionately less room for the current. And, by the latter experiment, we learn, that the electric matter is capable of displacing the calorific from that part of the metal which is occupied as a channel for the current, which, by its momentum compresses it into a state of density capable of igniting that portion of the wire in which it is imprisoned. The action in this case, although of an electric origin, may be justly compared to any other mode of compressing the calorific matter; and the effect is parallel to the ignition of tinder in the cylinder and piston apparatus; and to the ignition of a nail by the blacksmith's hammer; and there can be no doubt whatever, but that the distinction between the electric and calorific elements, will be still farther proved as we progress in discoveries in these departments of physical science.

FINIS.

APPENDIX.

ANATOMICAL OBSERVATIONS ON THE TORPEDO.

By John Hunter, F.R.S. *

I WAS desired some time since, by Mr. Walsh, whose experiments at La Rochelle had determined the effect of the torpedo to be electrical, to dissect and examine the peculiar organs by which that animal produces so extraordinary an effect. This I have done in several subjects furnished to me by that gentleman. I am now desired by him to lay before the society, the observations I have made; and for the better understanding of them, to present, on his part, a male and female torpedo in spirits; in the latter of which the electric organs are exposed in different views and sections; likewise a copper-plate, which he took care to have engraved, exhibiting those organs.

Of the general structure and anatomy of the torpedo I say nothing, since the animal does not differ very materially, excepting in its electric organs, as they have been very properly named by Mr. Walsh, from the rest of the rays, of which family it is well known to be. I will only premise, that the torpedo, of which I treat, is about 18 inches long, 12 broad, and, in its central or thickest part, 2 inches thick; which is nearly the size of the female specimen, now presented to the society, as well as of that from which the plate was taken: but where there is any difference in the organ arising from difference in size, notice will be taken of it in this account.

The electric organs of the torpedo are placed on each side of the cranium and gills, reaching from thence to the semicircular cartilages of each great fin, and extending longitudinally from the anterior extremity of the animal to the transverse cartilage, which divides the thorax from the abdomen; and within these limits they occupy the whole space between the skin of the upper and of the under surfaces; they are thickest at the edges near the centre of the fish, and become gradually

* Philosophical Transactions of the Royal Society.

thinner towards the extremities. Each electric organ, at its inner longitudinal edge, is unequally hollowed; being exactly fitted to the irregular projections of the cranium and gills. The outer longitudinal edge is a convex elliptic curve. The anterior extremity of each organ, makes the section of a small circle; and the posterior extremity makes nearly a right angle with the inner edge. Each organ is attached to the surrounding parts by a close cellular membrane, and also by short and strong tendinous fibres, which pass directly across, from its outer edge, to the semicircular cartilages.

They are covered, above and below, by the common skin of the animal; under which there is a thin fascia spread over the whole organ. This is composed of fibres, which run longitudinally, or in the direction of the body of the animal: these fibres appear to be perforated in innumerable places; which gives the fascia the appearance of being fasciculated; its edges all around, are closely connected to the skin, and at last appear to be lost, or to degenerate into the common cellular membrane of the skin. Immediately under this, is another membrane, exactly of the same kind, the fibres of which in some measure decussate those of the former, passing from the middle line of the body outwards and backwards. The inner edge of this is lost with the first described; the anterior, outer, and posterior edges, are partly attached to the semicircular cartilages, and partly lost in the common cellular membrane.

This inner fascia appears to be continued into the electric organ, by so many processes, and thereby makes the membranous sides or sheaths of the columns which are presently to be described; and between these processes the fascia covers the end of each column, making the outermost or first partition. Each organ, of the fish under consideration, is about five inches in length, and at the anterior end three in breadth, though it is but little more than half as broad at the posterior extremity. Each consists wholly of perpendicular columns, reaching from the upper to the under surface of the body, and varying in their lengths, according to the thickness of the parts of the body where they are placed; the longest column being about an inch and a half, the shortest about a quarter of an inch in length, and their diameters about nine-tenths of an inch.

The figures of the columns are very irregular, varying according to situation and other circumstances. The greatest number of them are either irregular hexagons, or irregular pentagons; but from the irregularity of some of them, it happens that a pretty regular quadrangular column is sometimes formed. Those of the exterior row are either quadrangular or hexagonal; having one side external, two lateral, and either one or two internal. In the second row they are mostly pentagons. Their coats are very thin, and seem transparent, closely connected with each other, having a kind of loose network of tendinous fibres, passing transversely and obliquely, between the columns, and uniting them more firmly together. These are mostly observable where the large trunks of the nerves pass. The columns are also attached by strong inelastic fibres, passing directly from the one to the other.

The number of columns in different torpedos, of the size of that now offered to the society, appeared to be about 470 in each organ; but the number varies according to the size of the fish. These columns increase, not only in size, but in number, during the growth of the animal: new ones forming perhaps every year on the exterior edges, as there they are much the smallest. This process may be similar to the formation of new teeth in the human jaw, as it increases. Each column is divided by horizontal partitions, placed over each other, at very small distances, and forming numerous interstices, which appear to contain a fluid. These partitions consist of a very thin membrane, considerably transparent. Their edges appear to be attached to one another, and the whole is attached by a fine cellular membrane to the inside of the columns. They are not totally detatched from one another: I have found them adhering, at different places, by blood vessels passing from one to another.

The number of partitions contained in a column of one inch in length, of a torpedo which had been preserved in proof spirit, appeared on a careful examination to be 150: and this number in a given length of column, appears to be common to all sizes in the same state of humidity; for by drying them they may be greatly altered: whence it appears probable that the increase in the length of a column, during the growth of the animal, does not enlarge the distance between each partition in proportion to

that growth; but that new partitions are formed, and added to the extremity of the column from the fascia.

The partitions are very vascular; the arteries are branches from the veins of the gills, which convey the blood that has received the influence of respiration. They pass along with the nerves to the electric organ, and enter with them; they then ramify, in every direction, into innumerable small branches on the sides of the columns, sending in from the circumference all around, on each partition, small arteries, which ramify and anastomose on it; and passing also from one partition to another, anastomose with the vessels of the adjacent partitions. The veins of the electric organ pass out, close to the nerves, and run between the gills, to the auricle of the heart.

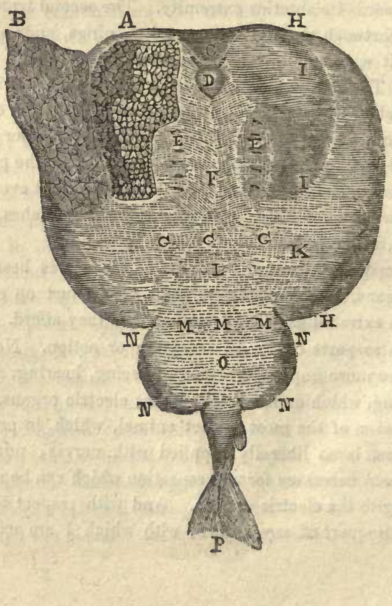
The nerves inserted into each electric organ, arise by three very large trunks, from the lateral and posterior part of the brain. The first of these, in its passage outwards, turns round a cartilage of the cranium, and sends a few branches to the first gill, and to the anterior part of the head, and then passes into the organ towards its anterior extremity. The second trunk enters the gills between the first and second openings, and, after furnishing it with small branches, passes into the organ near its middle. The third trunk, after leaving the skull, divides into two branches, which pass to the electric organ through the gills; one between the second and third openings, the other between the third and fourth, giving small branches to the gill itself. These nerves, having entered the organs, ramify in every direction, between the columns, and send in small branches, on each partition, where they are lost.

The magnitude and the number of the nerves bestowed on these organs, in proportion to their size, must on reflection appear as extraordinary as the phenomena they afford. Nerves are given to parts either for sensation or action. Now if we except the more important senses of seeing, hearing, smelling, and tasting, which do not belong to the electric organs, there is no part, even of the most perfect animal, which, in proportion to its size, is so liberally supplied with nerves; nor do the nerves seem necessary for any sensation which can be supposed to belong to the electric organs. And with respect to action, there is no part of any animal, with which I am acquainted,

however strong and constant its natural actions may be, which has so great a proportion of nerves. If it be then probable, that those nerves are not necessary for the purposes of sensation, or action, may we not conclude that they are subservient to the formation, collection, or management of the electric fluid; especially as it appears evident, from Mr. Walsh's experiments, that the will of the animal does absolutely control the electric powers of its body; which must depend on the energy of the nerves. How far this may be connected with the power of the nerves in general, or how far it may lead to an explanation of their operations, time and future discoveries alone can fully determine.

Fig. 100, is a view of the under surface of the female torpedo: A, an exposure, on flaying off the skin of the right electric organ, which consists of white bliant columns, in a close, and for the most part hexagonal arrangement, giving the general appearance of a honeycomb in miniature. These columns have

Fig. 100.



been sometimes denominated cylinders; but, having no interstices, they are all angular, and chiefly six-cornered:—B, the skin which covered the organ, showing on its inner side a hexagonal net work; C, the nostrils in the form of a crescent; D, the mouth in a crescent contrary to that of the nostrils, furnished with several rows of very small hooked teeth; E, the branchial apertures, five on each side; F, the place of the heart; G G G, the place of the two anterior transverse cartilages, which, passing one above and the other below the spine, support the diaphragm, and uniting towards their extremities, form on either side a kind of clavicle and scapula; H H, the outward margin of the great lateral fin; I I, its inner margin, confining with the electric organ; K, the articulation of the great lateral fin with the scapula; L, the abdomen; M M M, the place of the posterior transverse cartilage, which is single, united with the spine, and supports on each side the smaller lateral fins; N N N N, the two smaller lateral fins; O, the anus; P, the fin of the tail.

Fig. 101.

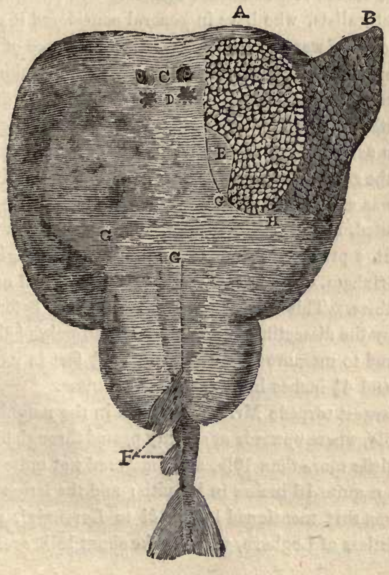


Fig. 101 is a view of the upper surface of the female torpedo; A A, an exposure of the upper part of the right electric organ; B, the skin which covered the organ; C, the eyes, prominent and looking horizontally outwards, but capable of being occasionally withdrawn into their sockets; D, two circular apertures communicating with the mouth, and furnished each with a membrane, which in air, as well as in water, plays regularly backwards and forwards across the aperture in the office of inspiration; E, the place of the right branchia; F, the two fins of the back; G G, the place of the anterior transverse cartilages.

OF THE TORPEDOS FOUND ON THE COAST OF ENGLAND.

By John Walsh, Esq. F.R.S.

It has lately been found, that the torpedo, or electric ray, frequents the shores of this island, contrary to a received opinion among naturalists, who have in general considered it as an inhabitant only of warmer climates. In consequence of inquiries Mr. W. had set on foot in some of our southern fishing ports, two torpedos, taken in Torbay, one in the beginning of August, and the other in the beginning of November, last year, (1773), have been actually sent up to this metropolis. The first, procured by the good offices of Mr. Amyatt, apothecary, in Berkeley-square, was examined, and the electrical organs were successfully injected, by Mr. John Hunter. The second, forwarded by Mr. Grant, a principal fishmonger in the land carriage branch, then at Brixham, came up very fresh and perfect, in one of his fish machines. This was weighed and measured before it was touched by the dissecting knife, and found to weigh 53lb. avoirdupois, and to measure 4 feet in length, 2½ feet in its extreme breadth, and 4½ inches in its extreme thickness.

The largest torpedo Mr. W. met with in the neighbourhood of Rochelle, where upwards of seventy passed through his hands, weighed little more than 10lb. and measured not quite 2 feet in length, nor quite 16 inches in breadth: and the largest he had read of was that mentioned by Rhedi to Lorenzini, weighing 24lb. doubtless of Leghorn, which make about 18lb. avoirdupois,

Though this Mediterranean torpedo has been ever considered as of an extraordinary size, it is exceeded in weight nearly three to one by our enormous British torpedo.

Its back was of a dark ash colour, with somewhat of a purple cast, but not at all mottled like those of the Atlantic coast of France, nor regularly marked with eyes, as they have been called, like some found in the Mediterranean. Its under part was white, skirted however with the same ash colour, which towards the tail became almost universal. The side fins, being a little contracted and curled up, prevented the precise measurement of its breadth, but it appeared to hold the general proportion observed in those of Rochelle; that is, the breadth was two-thirds of the length. Its electric organs likewise were proportionate with theirs, each organ measuring 15 inches in extreme length, and 8 in extreme breadth. In short, the torpedo of Torbay, no way differed from those seen in the Bay of Biscay, but in size and colour: and perhaps this difference may be thought rather casual than denoting a specific distinction.

It was a female, without any signs of pregnancy. The intestines contained, with some black slime, two vertebræs of a fish, seemingly of the cod kind. The electric organs of this torpedo were likewise injected by Mr. Hunter, though not with his first success, from the bursting of the artery in the operation; he determined however the number of columns, in one organ, to amount to 1182, and fully confirmed the observation he formerly made, that their numerous horizontal partitions were very vascular.

The frequent, and perhaps favourite situation of the torpedo, is to lie in concealment under sand. If it be placed by design, as it is sometimes left by accident, in any hollow of a sandy beach, whence the tide has just retired, it swims to that brink where the water is still draining away, and on finding itself unable, after repeated attempts, to push itself over the shallow, and follow the course of the tide, it begins with admirable address to bury itself in the sand, and by a gentle but quick flapping of its extremities all round, soon sinks itself a bed, and in the action throws the sand in a light shower over its back. Neither the animal nor the spot it is in can now be distinguished; save

only that, on a nice search, its two small inspiratory foramina, and their membranes at play, may be perceived. It is in this situation that the torpedo gives his most forcible shock, which throws down the astonished passenger who inadvertently steps on him.

Mr. W. has thus shown that Great Britain, too, claims the torpedo, or electric ray; that ours is the broad marine sort, which Socrates, as Meno thought, resembled; and that it is the black torpedo, whose influence subdues obstinate head-aches, and the gout itself.* In announcing to our naturalists and electricians the presence of this wonderful guest, Mr. W. says he should certainly felicitate our individuals on their acquisition, but that the Leyden Phial contains all his magic power.

EXPERIMENTS ON THE TORPEDO, MADE AT LEGHORN, JAN. 1, 1773.

By Dr. John Ingenhousz, F.R.S.

As I could get no torpedos alive to my lodgings at Leghorn, I hired a fishing vessel, called a tartana, with 18 men, and went out 20 miles to sea, where the bottom is muddy, and where those fish are chiefly to be found. We caught five; of which four were about a foot in length, and the other of a smaller size. Before the nets were taken up, I charged a coated jar by a glass tube, and gave a shock to some of the sailors, who all said that they felt the same sensation as when they touched the torpedo. They also said, that this animal has but very little force in winter, and cannot live a long time out of the water. I put the torpedos immediately into a tub, filled with sea water, together with two or three other fishes, which I found not at all hurt by their company. I took one of the torpedos in my hand, so that my thumbs pressed gently the upper side of those two soft bodies at the side of the head, called (perhaps very improperly) musculi falcati by Redi and Lorenzini, while my fore-fingers pressed the opposite side. About a minute or two after I felt a sudden trembling in my thumbs, which extended no farther than

* Scribonius Largus, cap. i, and xli. See also several of the early physicians, Roman and Arabian, for different cures attributed by them to the effect of the torpedo.

my hands: this lasted about two or three seconds. After some seconds more, the same trembling was felt again. Sometimes it did not return in several minutes, and then came again at very different intervals. Sometimes I felt the trembling both in my fingers and thumb. These tremors gave me the same sensation as if a great number of very small electrical bottles were discharged through my hand very quickly one after the other. The fish occasioned the shock, or trembling, as well out of the water as in it. The shock lasted sometimes scarcely a second; sometimes two or three seconds. Sometimes it was very weak; at other times so strong, that I was very near being obliged to quit my hold of the animal. The torpedo having given one shock, did not seem to lose the power of giving another of the same force soon after; for I observed several times, that the shocks, when they followed one another very fast, were stronger at last than in the beginning; and this was the same when the fish was under water as when kept out of it. The pressure of my fingers, more or less strong, did not seem to make any alteration in the powers of the torpedo. Applying a brass chain to the back of the fish, where I had put my thnmb before, I found no sensation at all in my hand, though I repeated the experiment often, and applied the chain for a space of time, in which I always perceived a stroke.* This was probably owing to the weakness of the fish in winter; or perhaps because I neglected to put my finger to its opposite side. Having insulated myself on an electrical stand, and keeping the torpedo in my hand, in the manner above-mentioned, I gave not the least sign of being electrified, whether I received a stroke from the fish or not. The torpedo being suspended by a clean and dry silk ribband, it attracted no light bodies, such as pith-balls, or others, put near it. A coated bottle applied to the fish, thus suspended, did not at all become charged. When the fish gave the shock in the dark, I heard no crackling noise, nor perceived any spark. When pinched with my nails, it did not give more or fewer strokes than when not pinched. But by folding his body, or

* Dr. Ingenhousz means, that he felt no shock, though he saw the animal, by the contortion of its body, give one to the chain. At that time he did not seem to know, that thongh the shock would be communicated by a rod of any metal, it could not be so by a chain, or where there was the least interruption of continuity.

bending his right side to his left side, I felt more frequent shocks. Dr. Drummond made these experiments with me.

We dissected some of the torpedos, and found, if I remember well, four very large bundles of nerves, passing sidewards from the head into the two soft bodies, called musculi falcati, and distributed by dense ramifications through their whole substance. These nerves seem to terminate in round threads, which surround certain cylinders of a transparent gelatinous substance, which seems to constitute the material part of these singular bodies that appear to be the reservoirs of the electric power: these cylinders are parallel to each other, and have their direction from the under to the upper side of the fish. I did not observe whether these soft bodies changed in size when the tordedo gives a shock, but I suspect they do.

AN ACCOUNT OF THE GYMNOTUS ELECTRICUS.

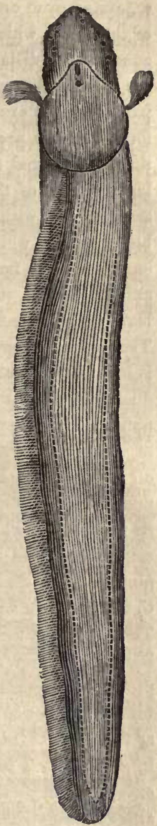
By John Hunter, F.R.S.

To Mr. Walsh, the first discoverer of animal electricity, the learned will be indebted for whatever the following pages may contain, either curious or useful. The specimen of the animal which they describe was procured by that gentleman, and at his request this dissection was performed, and this account of it is communicated.

This fish, on the first view, appears very much like an eel, from which resemblance it has most probably got its name; but it has none of the specific properties of that fish. This animal may be considered, both anatomically and physiologically, as divided into two parts, viz, the common animal part, and a part which is superadded, viz. the peculiar organ. I shall at present consider it only with respect to the last, as the first explains nothing relating to the other, nor any thing relating to the animal economy of fish in general. The first, or common animal part, is so contrived, as to exceed what was necessary for itself, in order to give situation, nourishment, and most probably the peculiar property to the second. The last part, or peculiar organ, has an immediate connexion with the first; the body affording it a situation, the heart nourishment,

and the brain, nerves, and probably its peculiar powers. For the first of these purposes, the body is extended out in length, being much longer than would be sufficient for what may be called its progressive motion. For the real body, or that part where the viscera and parts of generation lie, is situated, with respect to the head, as in other fish, and is extremely short; so that, according to the ordinary proportions, this should be a very short fish. Its great length, therefore, seems chiefly intended to afford a surface for the support of the peculiar organ; however, the tail part is likewise adapted to the progressive motion of the whole, and to preserve the specific gravity; for the spine, medulla spinalis, muscles, fin, and air bladder, are continued through its whole length. Besides which parts, there is a membrane passing from the spine to that fin which runs along the belly or lower edge of the animal. This membrane is broad at the end next the head, terminating in a point at the tail. It is a support for the abdominal fin, gives a greater surface of support for the organ, and makes a partition between the organs of the two opposite sides.

Fig. 102.



The Organs.—The organs which produce the peculiar effect of this fish, constitute nearly one-half of that part of the flesh in which they are placed, and perhaps make more than one-third of the whole animal. There are two pair of these organs, a larger, and a smaller; one being placed on each side. The large pair occupy the whole lower or anterior, and also the lateral part of the body, making the thickness of the fore or lower parts of the animal, and run almost through its whole length; viz. from the abdomen to near the end of the tail. It is broadest on the sides of the fish at the anterior end, where it encloses more of

the lateral parts of the body, becomes narrower towards the end of the tail, occupying less and less of the sides of the animal, till at last it ends almost in a point. These two organs are separated from one another at the upper part, by the muscles of the back, which keep their posterior or upper edges at a considerable distance from one another; below that, and towards the middle, they are separated by the air bag; and at their lower parts they are separated by the middle partition. They begin forwards, by a pretty regular edge, almost at right angles with the longitudinal axis of the body situated on the lower and lateral parts of the abdomen. Their upper edge is a pretty straight line, with small indentations made by the nerves and blood vessels, which pass round it to the skin. At the anterior end they go as far towards the back as the middle line of the animal; but in their approach towards the tail they gradually leave that line, coming nearer to the lower surface of the animal. The general shape of the organ, on an external or side view, is broad at the end next the head of the animal, becoming gradually narrower towards the tail, and ending there almost in a point. The other surfaces of the organ are fitted to the shape of the parts with which they come in contact; therefore, on the upper and inner surface it is hollowed, to receive the muscles of the back. There is also a longitudinal depression on its lower edge, where a substance lies, which divides it from the small organ, and which gives a kind of fixed point for the lateral muscles of the fin. Its most internal surface is a plane adapted to the partition which divides the two organs from one another. The edge next the muscles of the back is very thin, but the organ becomes thicker and thicker towards its middle, where it approaches the centre of the animal. It becomes thinner again, towards the lower surface or belly; but that edge is not so thin as the other. Its union with the parts to which it is attached is in general by a loose, but pretty strong, cellular membrane; except at the partition, to which it is joined so close as to be almost inseparable.

The small organ lies along the lower edge of the animal, nearly to the same extent as the other. Its situation is marked externally by the muscles which move the fin under which it lies. Its anterior end begins nearly in the same line with the

large organ, and just where the fin begins. It terminates almost insensibly near the end of the tail, where the large organ also terminates. It is of a triangular figure, adapting itself to the part in which it lies. Its anterior end is the narrowest part; towards the tail it becomes broader; in the middle of the organ it is thickest; and from thence becomes gradually thinner to the tail, where it is very thin. The two small organs are separated from one another by the middle muscle, and by the bones on which the bones of the fins are articulated. The large and the small organ on each side, are separated from one another by a membrane, the inner edge of which is attached to the middle partition, and its outer edge is lost on the skin of the animal. To expose the large organ to view, nothing more is necessary than to remove the skin, which adheres to it by a loose cellular membrane. But to expose the small organ, it is necessary to remove the long row of small muscles which move the fin.

Of the structure of these Organs.—The structure is extremely simple and regular, consisting of two parts; viz. flat partitions or septa, and cross divisions between them. The outer edge of these septa appear externally in parallel lines nearly in the direction of the longditudinal axis of the body. These septa are thin membranes, placed nearly parallel to one another. Their lengths are nearly in the direction of the long axis, and their breadth is nearly the semidiameter of the body of the animal. They are of different lengths, some being as long as the whole organ. I shall describe them as beginning principally at the anterior end of the organ, though a few begin along the upper edge; and the whole, passing towards the tail, gradually terminate on the lower surface of the organ; the lowermost at their origin terminating soonest. Their breadths differ in different parts of the organ. They are in general broadest near the anterior end, answering to the thickest part of the organ, and become gradually narrower towards the tail, however, they are very narrow at their beginnings or anterior ends. Those nearest the muscles of the back are the broadest, owing to their curved or oblique situation on these muscles, and get gradually narrower towards the lower part, which is in a great measure owing to their becoming more transverse, and also to the organ becoming thinner at that place. They have an

outer and an inner edge. The outer is attached to the skin of the animal, to the lateral muscles of the fin, and to the membrane which divides the great organ from the small; and the whole of their inner edges are fixed to the middle partition formerly described, also to the air bladder, and three or four terminate on that surface which incloses the muscles of the back. These septa are at the greatest distance from one another at their exterior edges near the skin, to which they are united; and as they pass from the skin towards their inner attachments, they approach one another. Sometimes we find two uniting into one. On that side next the muscles of the back, they are hollow from edge to edge, answering to the shape of those muscles; but become less and less so towards the middle of the organ; and from that towards the lower part of the organ, they become curved in the other direction. At the anterior part of the large organ, where it is nearly of an equal breadth, they run pretty parallel to one another, and also pretty straight; but where the organ becomes narrower, it may be observed in some places, that two join or unite into one; especially where a nerve passes across. The termination of this organ at the tail is so very small, that I could not determine whether it consisted of one septum or more. The distances between these septa will differ in fishes of different sizes. In a fish of two feet four inches in length, I found them to be about one twenty-seventh cf an inch distant from one another; and the breadth of the whole organ, at the broadest part, about an inch and a quarter, in which space were thirty-four septa. The small organ has the same kind of septa, in length passing from end to end of the organ, and in breadth passing quite across; they run somewhat serpentine, not exactly in straight lines. Their outer edges terminate on the outer surface of the organ, which is in contact with the inner surface of the external muscle of the fin, and their inner edges are in contact with the centre muscles. They differ very much in breadth from one another; the broadest being equal to one side of the triangle, and the narrowest scarcely broader than the point or edge. They are pretty nearly at equal distances from one another; but much nearer than those of the large organ, being only about one fifty-sixth part of an inch asunder: but they are at a

greater distance from one another towards the tail, in proportion to the increase of breadth of the organ. The organ is about half an inch in breadth, and has 14 septa. These septa, in both organs, are very tender in consistence, being easily torn. They appear to answer the same purpose with the columns in the torpedo, making walls or butments for the sub-divisions, and are to be considered as making so many distinct organs. These septa are intersected transversely by very thin plates or membranes, whose breadth is the distance between any two septa, and therefore of different breadths in different parts; breadest at the edge which is next to the skin; narrowest at that next to the centre of the body, or to the middle partition which divides the two organs from one another. Their lengths are equal to the breadths of the septa, between which they are situated. There is a regular series of them continued from one end of any two septa to the other. They appear to be so close as even to touch. In an inch in length there are about 240, which multiplies the surface in the whole to a vast extent.

Of the Nerves.—The nerves in this animal may be divided into two kinds; the first, appropriated to the general purposes of life; the second, for the management of this peculiar function, and very probably for its existence. They arise in general from the brain and medulla spinalis, as in other fish; but those from the medulla are much larger than in fish of equal size, and larger than is necessary for the common operations of life. The nerve which arises from the brain, and passes down the whole length of the animal (which I believe exists in all fish) is larger in this than in others of the same size, and passes nearer the spine. In the common eel it runs in the muscles of the back, about midway between the skin and spine. In the cod it passes immediately under the skin. From its being larger in this fish than in others of the same size, one might suspect, that it was intended for supplying the organ in some degree; but this seems not to be the case, as I was not able to trace any nerves going from it to join those from the medulla spinalis, which run to the organ. This nerve is as singular an appearance as any in this class of animals; for surely it must appear extraordinary, that a nerve should arise from the brain to be lost in common parts, while

there is a medulla spinalis giving nerves to the same parts. It must still remain one of the inexplicable circumstances of the nervous system. The organ is supplied with nerves from the medulla spinalis, from which they come out in pairs between all the vertebræ of the spine. In their passage from the spine they give nerves to the muscles of the back, &c. They bend forwards and outwards on the spine, between it and the muscles, and send out small nerves to the external surface, which join the skin near to the lateral lines. These ramify on the skin, but are principally bent forwards between it and the organ, into which they send small branches as they pass along. They seem to be lost in these two parts. The trunks get upon the air-bladder, or rather dip between it and the muscles of the back, and continuing their course forwards on that bag, they dip in between it and the organ, where they divide into smaller branches; they then get upon the middle partition, on which they continue to divide into still smaller branches; after which they pass on, and get upon the small bones and muscles, which are the bases for the under fin, and at last they are lost on that fin. After having got between the organ and the above-mentioned parts, they are constantly sending small nerves into the organs; first into the great organ, and then into the small one; also into the muscles of the fin, and at last into the fin itself. These branches, which are sent into the organ as the trunk passes along, are so small, that I could not trace their ramifications in the organs. In this fish, as well as in the torpedo, the nerves which supply the organ are much larger than those bestowed on any other part for the purposes of sensation and action; but it appears to me, that the organ of the torpedo is supplied with much the largest proportion. If all the nerves which go to it were united together, they would make a vastly greater chord, than all those which go to the organ of this eel. Perhaps when experiments have been made on this fish, equally accurate with those made on the torpedo, the reason for this difference may be assigned.

Blood Vessels.—How far this organ is vascular, I cannot positively determine; but from the quantities of small arteries going to it, I am inclined to believe, that it is not deficient in vessels. The arteries arise from the large artery which passes

down the spine; they go off in small branches like the intercostals in the human subject, pass round the air bladder, and get upon the partition together with the nerves, and distribute their branches in the same manner. The veins take the same course backwards, and enter the large vein which runs parallel with the artery.

Fig. 102 is a representation of the animal lying on one side, which posture exposes the whole of the under fin. The head is twisted, to show its upper part, on which are seen the eyes, &c.

It is now the general opinion of philosophers, that the electric organs of the torpedo and the gymnotus, consist of series of Galvanic pairs, in a proper battery arrangement: and this opinion is fully supported by the fact, that electric piles, of alternate layers of muscle and brain, have been made. The shock from the eel is precisely that of a Voltaic battery; that is, it consists of several distinct shocks, given in such rapid succession that the hands cannot get clear of the water before it receives a kind of volley of discharges.

Dr. John Davy, and also his brother, Sir Humphry, made several experiments on the torpedo; by which they obtained sparks and electric currents: and Dr. Faraday observed similar phenomena whilst experimenting on the gymnotus, belonging to the Adelaide Gallery.

"The Indians entertain such a dread of the Gymnotus, and show so much reluctance to approach it when alive and active, that Humboldt, when in South America, found great difficulty in procuring a few to experiment upon. For this express purpose he stopped some days on his journey across the *Llanos* to the river Apuré, at the small town of Calaboze, in the neighbourhood of which, he was informed, that they were very numerous. But, though his landlord took the utmost pains to gratify his wish, he was constantly unsuccessful. At last he determined to proceed, himself, to the spot, and was conducted to a piece of shallow water, stagnant and muddy, but of the heat of 79 degrees, surrounded by a rich vegetation of the great Indian fig trees and odoriferous sensitive plants. Here

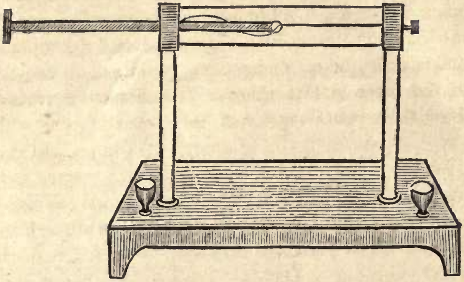
he soon witnessed a spectacle of the most novel and extraordinary kind. About thirty horses were quickly collected from the adjacent savannahs, where they run half wild. These the Indians drove into a marsh. The *Gymnoti*, roused from their slumbers by the noise and tumult, mount near the surface, and swimming like so many livid water serpents, briskly pursue the intruders, and gliding under their bellies, discharge through them the most violent shocks. The horses, convulsed and terrified, their manes erect, and their eyes starting with pain and anguish, made unavailing struggles to escape. In less than five minutes, two of them sunk under the water, and were drowned. Victory seemed to declare for the electric Eels. But their activity now began to relax. Fatigued by such expense of nervous energy, they shot their electric discharges with less frequency and effect. The surviving horses gradually recovered from the shocks, and became more composed and vigorous. In a quarter of an hour the *Gymnoti* finally retired from the contest, and in such a state of langour and complete exhaustion, that they were easily dragged on shore, by the help of small harpoons fastened to cords."

The Gymnotus Electricus is a native of the warmer regions of America and Africa. It inhabits the larger rivers of Surinam, and also several of the stagnant pools of that country. In Africa it is said to inhabit the branches of the Senegal. The Torpedo is found in greatest abundance in the Mediterranean sea, on the coast of France and Italy.

A convenient instrument for comparing the powers of batteries, in igniting different lengths of the same wire, being overlooked in Lecture XII., will be described in this place. It is represented by fig. 203, and consists of a wide glass tube, supported horizontally by two brass pillars on a mahogany baseboard. The tube is capped with brass at both ends, and along its axis passes the platinum wire to be operated on; and which is fixed to both brass caps. Through the centre of one of these caps slides a stout copper wire, the outermost end of which is furnished with a milled button, and the inner end with a loop. The platinum wire passes through this loop, which, by sliding to and fro, leaves any required portion of the platinum, between

itself and the other end of tube, unprotected, and subject to the whole of the battery current; whilst the other portion is

Fig. 203.



protected by the thick sliding wire, which conducts the greater portion of the current from the loop to the socket in which it slides. The current is led to and from the brass caps by the brass supports and wires which terminate in the cups. When a battery is connected with this instrument, we can soon ascertain what length of *the* wire it will ignite, by moving the sliding wire one way or the other till the unprotected platinum is seen just red hot throughout. The instrument which we had from Mr. Watkins, Charing Cross, and whose invention I believe it is, had a tube about 12 inches long. The wire which we first employed being too thin for powerful batteries, fused into multitudes of globules the first time that Grove's series of 50 pairs was laid on.

There are several other instruments, and many more experiments, which could not be conveniently introduced to this *elementary* course. They will be arranged in a *supplementary* course, that will be devoted to the more abstruse phenomena of Electro-Chemistry, and other departments of Galvanism; and will also touch on some of those glaring errors which have recently made their appearance in this branch of Physics.

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